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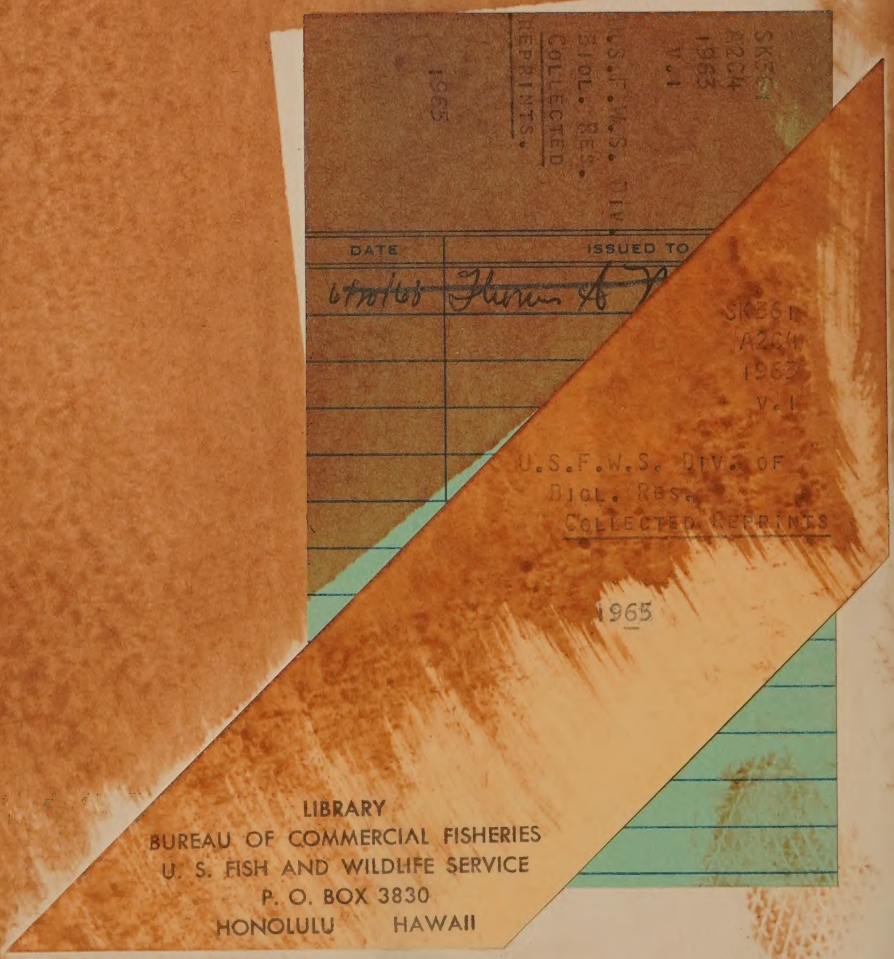
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1. ABEGGLEN, CARL E.
A review of "Whales," by E. J. Slijper. Atlantic Naturalist, vol. 18, no. 2, p. 136, April-June 1963.

2. _____, ALTON Y. ROPPEL, AND DALE W. RICE 1/
Marine mammals. In: Maurice E. Stansby (editor), Industrial Fishery Technology, Reinhold Publishing Corporation, New York, ch. 15, p. 209-216, 1963.

3. AHLSTROM, ELBERT H.
Review of "Tropical Inland Fisheries," by C. F. Hickling. The Quarterly Review of Biology, vol. 38, no. 4, p. 426, December 1963.

4. _____, AND JAMES R. THRAILKILL
Plankton volume loss with time of preservation. California Cooperative Oceanic Fisheries Investigations Reports, Volume IX, July 1, 1960 - June 30, 1962, p. 57-73, January 1963.

5. AMOS, MURRAY H., RAYMOND E. ANAS, AND ROGER E. PEARSON
Use of a discriminant function in the morphological separation of Asian and North American races of pink salmon, Oncorhynchus gorbuscha (Walbaum). International North Pacific Fisheries Commission, Document 412, Bulletin No. 11, p. 73-100, 1963.

6. ANAS, RAYMOND E.
Red salmon scale studies. International North Pacific Fisheries Commission Annual Report 1961, p. 114-116, 1963.

7. AUSTIN, THOMAS S.
International Cooperation-Equalant. American Institute of Biological Sciences, vol. 13, no. 5, p. 46-48, October 1963.

1/ Reprints not available.

8. BAXTER, KENNETH N.
Abundance of postlarval shrimp - one index of future shrimping success. Proceedings of the Gulf and Caribbean Fisheries Institute, Fifteenth Annual Session, November 1962, p. 79-87, June 1963.

9. BEETON, ALFRED M.
Limnological survey of Lake Erie, 1959 and 1960. Great Lakes Fishery Commission, Technical Report No. 6, 32 p., November 1963.

10. _____, AND DAVID C. CHANDLER
The St. Lawrence Great Lakes. Limnology in North America, University of Wisconsin Press, p. 535-558, 1963.

11. BERRY, FREDERICK H.
Caranx fasciatus Cuvier, an unidentifiable name for a carangid fish. Copeia, no. 3, p. 583-585, September 1963.

12. _____, AND IZADORE BARRETT
Gillraker analysis and speciation in the thread herring genus Opisthonema. Inter-American Tropical Tuna Commission Bulletin, vol. 7, no. 2, p. 113-190, 1963.

13. BLAHM, THEODORE H.
Passage of salmon fingerlings through small tunnels. Transactions of the American Fisheries Society, vol. 92, no. 3, p. 302-303, July 1963.

14. BOYAR, H. C.
Scales and earstones reveal age of Atlantic herring. Maine Field Naturalist, vol. 19, no. 3, 2 p., March 1963.

15. BROCK, VERNON E.
Will tuna research change direction? Proceedings of the Gulf and Caribbean Fisheries Institute, Fifteenth Annual Session, November 1962, p. 50-52, June 1963.

16. _____
Developing tropical Atlantic fisheries through international research. Proceedings of the Gulf and Caribbean Fisheries Institute, Fifteenth Annual Session, November 1962, p. 152-155, June 1963.

17. BROCK, VERNON E.
The International Cooperative Investigation of the Tropical Atlantic. Interagency Committee on Oceanography of the Federal Council for Science and Technology, ICO Pamphlet No. 11, Appendix A., p. 33-37, April 1963.

18. BUTLER, PHILIP A., AND PAUL F. SPRINGER
Pesticides - a new factor in coastal environments. Transactions of the Twenty-eighth North American Wildlife and Natural Resources Conference, March 4, 5, and 6, 1963, p. 378-390, 1963.

19. CALLAWAY, RICHARD J.
Ocean conditions in the vicinity of the Aleutian Islands, summer 1957. International North Pacific Fisheries Commission, Document No. 413, Bulletin No. 11, p. 1-29, 1963.

20. CARR, J. F., A. M. BEETON, AND H. ALLEN
Factors associated with low dissolved oxygen concentrations in Lake Erie. (Abstract) Proceedings of Sixth Conference on Great Lakes Research, p. 133, 1963.

21. _____, AND JARL K. HILTUNEN
Changes in the bottom fauna of Lake Erie west of the islands, 1930-1961. (Abstract) Proceedings of Sixth Conference on Great Lakes Research, p. 268, 1963.

22. CHAMBERLIN, J. LOCKWOOD, AND FRANKLIN STEARNS 1/
A geographic study of the clam, Spisula polynyma (Stimpson). Serial Atlas of the Marine Environment, Folio 3, p. 1-12, 1963.

23. CLARK, JOHN R.
Size selection of fish by otter trawls, results of recent experiments in the Northwest Atlantic. International Commission for the Northwest Atlantic Fisheries, North Atlantic Fish Marking Symposium, Woods Hole, Massachusetts, May 1961, Special Publication no. 5, p. 24-96, 1963.

24. CLEAVER, FRED C.
Bering Sea king crab (Paralithodes camtschatica) tagging experiments. International Commission for the Northwest Atlantic Fisheries, North Atlantic Fish Marking Symposium, Woods Hole, Massachusetts, May 1961, Special Publication no. 4, p. 59-63, 1963.

1/ Reprints not available.

25. CLENCH, W. J., AND A. S. MERRILL
Some shell malformations. Shells and Their Neighbors, no. 16, p. 1-2, 1963.

26. COHEN, DANIEL M.
A new genus and species of bathypelagic ophidioid fish from the Western North Atlantic. Breviora, no. 196, 8 p., December 31, 1963.

27. _____
The publication dates of Goode and Bean's "Oceanic Ichthyology." Journal of the Society for the Bibliography of Natural History, vol. 4, part 3, p. 162-166, November 1963.

28. _____, AND MENICO TORCHIO
Comments on the identity of the Mediterranean fish Strinsia tinca. Annals and Magazine of Natural History, series 13, vol. 6, p. 389-390, July 1963.

29. COLLETTE, BRUCE B.
Review of "Collected Works, Volume IV, Ichthyology," by L. S. Berg. Copeia, no. 1, p. 215-216, March 1963.

30. _____
The systematic status of the Gulf of Mexico butterfish Porontus burti (Fowler). Copeia, no. 3, p. 582-583, September 1963.

31. _____
The first record of the short bigeye, Pseudopriacanthus altus, from the Caribbean Sea. Copeia, no. 3, p. 591, September 1963.

32. _____
The subfamilies, tribes, and genera of the Percidae (Teleostei). Copeia, no. 4, p. 615-623, December 1963.

33. _____, AND ROBERT H. GIBBS
A preliminary review of the fishes of the family Scombridae. Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species, Methodological Paper IA, FAO Fisheries Reports, Rome, 1963, vol. 1, no. 6, p. 23-32, 1963.

34. _____ _____
Preliminary field guide to the mackerel-and tuna-like fishes of the Indian Ocean (Scombridae). Smithsonian Institution, Washington, D. C., 48 p., 1963.

35. COLLETTE, BRUCE B., FRANK H. TALBOT, AND RICHARD H. ROSENBLATT
The first California record of sierra Scomberomorus sierra Jordan and Starks. California Fish and Game, vol. 49, no. 1, p. 53-54, January 1963.

36. COLLINS, GERALD B.
Fish passage research in the Columbia River Basin. Transactions of the Twenty-eighth North American Wildlife and Natural Resources Conference, March 4, 5, and 6, 1963, p. 356-360, 1963.

37. COLTON, JOHN B., JR., AND KENNETH A. HONEY
The eggs and larval stages of the butterfish, Poronotus triacanthus. Copeia, no. 2, p. 447-450, June 1963.

38. COSTELLO, T. J.
The use of stains in shrimp mark-recapture experiments. International Commission for the Northwest Atlantic Fisheries North Atlantic Fish Marking Symposium, Woods Hole, Massachusetts, May 1961, Special Publication no. 4, p. 142-143, 1963.

39. CROWE, WALTER R., ERNEST KARVELIS, AND LEONARD S. JOERIS
The movement, heterogeneity, and rate of exploitation of walleyes in northern Green Bay, Lake Michigan, as determined by tagging. International Commission for the Northwest Atlantic Fisheries, North Atlantic Fish Marking Symposium, Woods Hole, Massachusetts, May 1961, Special Publication no. 4, p. 38-41, 1963.

40. DANIELS, S. L., L. L. KEMPE, E. S. GRAHAM, AND A. M. BEETON
Quantitation of microorganic compounds in waters of the Great Lakes by adsorption on activated carbon. Proceedings of the Sixth Conference on Great Lakes Research, p. 118-123, 1963.

41. DAVIS, HARRY C.
The effect of salinity on the temperature tolerance of eggs and larvae of some lamellibranch mollusks. (Abstract) Proceedings of the Sixteenth International Congress of Zoology, vol. 1, p. 226, 1963.

42. DODIMEAD, A. J., F. FAVORITE, AND T. HIRANO
Salmon of the North Pacific Ocean - Part II - Review of oceanography of the Subarctic Pacific Region. International North Pacific Fisheries Commission, Bulletin No. 13, p. 1-195, 1963.

43. DRAGOVICH, ALEXANDER
Hydrology and plankton of coastal waters at Naples, Florida. Quarterly Journal of the Florida Academy of Sciences, vol. 26, no. 1, p. 22-47, March 1963.

44. _____, AND JOHN A. KELLY, JR.
A biological study and some economic aspects of squid in Tampa Bay, Florida. Proceedings of the Gulf and Caribbean Fisheries Institute, Fifteenth Annual Session, November 1962, p. 87-102, June 1963.

45. EDWARDS, ROBERT L.
Report on the new Albatross IV. Proceedings of the Gulf and Caribbean Fisheries Institute, Fifteenth Annual Session, November 1962, p. 55-58, June 1963.

46. _____
Observations on the small mammals of the southeastern shore of Hudson Bay. The Canadian Field-Naturalist, vol. 77, no. 1, p. 1-12, January-March 1963.

47. ENGLE, DAVID W., AND EDNA M. DAVIS
The relationship of cellular blood components to activity in certain marine teleosts. (Abstract) American Zoologist, vol. 3, no. 4, p. 521, November 1963.

48. ENGLE, JAMES B., AND AARON ROSENFIELD
Progress in oyster mortality studies. Proceedings of the Gulf and Caribbean Fisheries Institute, Fifteenth Annual Session, November 1962, p. 116-124, June 1963.

49. FARRIS, DAVID
Shrinkage of sardine (Sardinops caerulea) larvae upon preservation in buffered formalin. Copeia, no. 1, p. 185-186, March 1963.

50. _____
Reproductive periodicity in the sardine (Sardinops caerulea) and the Jack mackerel (Trachurus symmetricus) on the Pacific Coast of North America. Copeia, no. 1, p. 182-184, March 1963.

51. FAVORITE, FELIX, AND MITCHELL G. HANAVAN
Oceanographic conditions and salmon distribution south of the Alaska Peninsula and Aleutian Islands, 1956. International North Pacific Fisheries Commission, Document No. 415, Bulletin No. 11, p. 57-72, 1963.

52. FAVORITE, FELIX, AND B. A. MORSE
Oceanography. International North Pacific Fisheries Commission Annual Report, 1961, p. 102-105, 1963.

53. FRENCH, ROBERT
Salmon distribution and abundance on the high seas. International North Pacific Fisheries Commission Annual Report 1961, p. 92-101, 1963.

54. FRITZ, RAYMOND L.
An analysis of silver hake tag returns. International Commission for the Northwest Atlantic Fisheries, North Atlantic Fish Marking Symposium, Woods Hole, Massachusetts, May 1961, Special Publication no. 4, p. 214-215, 1963.

55. GANGMARK, HAROLD A.
A view of the present status of spawning channels. Report of Second Governors' Conference on Pacific Salmon, convened by Governor Albert D. Rosellini of Washington, Hyatt House, Seattle, January 7-10, 1963, p. 105, 1963.

56. GILBERT, PERRY W., AND STEWART SPRINGER
Testing shark repellents. Sharks and Survival, D.C. Health, Boston, p. 477-494, 1963.

57. GOODING, REGINALD M.
The olfactory organ of the skipjack Katsuwonus pelamis. Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species, FAO Fisheries Reports No. 6, vol. 3, p. 1621-1631, 1963.

58. GRAHAM, H. W.
United States Research Report 1962. International Commission for the Northwest Atlantic Fisheries, Redbook, Part II, p. 104-125, December 1963.

59. HANKS, JAMES E.
Reproduction and larval development of the New England clam drill, Polinices duplicatus (Say) (Naticidae: Gastropoda). (Abstract) Proceedings of the Sixteenth International Congress of Zoology, vol. 1, p. 227, 1963.

60. HANKS, ROBERT W.
Chemical control of the green crab, Carcinus maenas (L). Proceedings of the National Shellfisheries Association for 1961, vol. 52, p. 75-86, 1963.

61. HANKS, ROBERT W.
Occurrence of an unusual mollusk on the coast of Maine. Maine Field Naturalist, vol. 19, no. 2, p. 22-23, February 1963.

62. HAYES, MURRAY L.
King crab tagging methods in Alaska. International Commission for the Northwest Atlantic Fisheries, North Atlantic Fish Marking Symposium, Woods Hole, Massachusetts, May 1961, Special Publication no. 4, p. 262-265, 1963.

63. HESTER, F. J., J. R. HUNTER, AND R. R. WHITNEY
Jumping and spinning behavior in the spinner porpoise. Journal of Mammalogy, vol. 44, no. 4, 2 p., November 1963.

64. HIDA, THOMAS S., AND ROBERT A. MORRIS
Preliminary report on the Marquesan sardine, Harengula vittata, in Hawaii. Pacific Science, vol. 17, no. 4, p. 431-437, October 1963.

Volume II

65. HILDEBRAND, SAMUEL F.
Family Elopidae. In: "Fishes of the Western North Atlantic," edited by Yngve H. Olsen. Memoir Sears Foundation for Marine Research, no. 1, part 3, p. 111-131, 1963.

66. _____
Family Albulidae. In: "Fishes of the Western North Atlantic," edited by Yngve H. Olsen. Memoir Sears Foundation for Marine Research, no. 1, part 3, p. 132-147, 1963.

67. _____
Family Engraulidae. In: "Fishes of the Western North Atlantic," edited by Yngve H. Olsen. Memoir Sears Foundation for Marine Research, no. 1, part 3, p. 152-249, 1963.

68. _____
Family Clupeidae. In: "Fishes of the Western North Atlantic," edited by Yngve H. Olsen. Memoir Sears Foundation for Marine Research, no. 1, part 3, p. 257-454, 1963.

69. HOSS, DONALD E.
Accumulation of radioactive gold by estuarine animals. (Abstract) Association of Southeastern Biologists Bulletin, vol. 10, no. 2, p. 30, April 1963.

70. HOWARD, GERALD V.
The matter of availability and the harvest of tunas. Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species, FAO Fisheries Reports No. 6, vol. 3, p. 1041-1055, 1963.

71. HUNTER, CHARLES, AND HERBERT LARKINS
North Pacific and Bering Sea winter gillnetting. Pacific Fisherman, vol. 61, no. 6, p. 7-9, 1963.

72. IVERSEN, ROBERT T. B., PAUL J. PERKINS, AND RICHARD D. DIONNE
An indication of underwater sound production by squid. Nature, vol. 199, no. 4890, p. 250-251, July 20, 1963.

73. JENSEN, ALBERT C.
APPENDIX I. A standard terminology and notation for otolith age readers. International Commission for the Northwest Atlantic Fisheries, Redbook, Part III, p. 131-134, December 1963.

74. _____
Further field experiments with tags for haddock. International Commission for the Northwest Atlantic Fisheries, North Atlantic Fish Marking Symposium, Woods Hole, Massachusetts, May 1961, Special Publication no. 4, p. 194-203, 1963.

75. JOHNSON, JAMES H.
Changes in availability of albacore in the eastern Pacific Ocean 1952 and 1958. Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species, FAO Fisheries Reports No. 6, vol. 3, p. 1227-1235, 1963.

76. JONES, EVERET C.
Tremoctopus violaceus uses Physalia tentacles as weapons. Science, vol. 139, no. 3556, p. 764-766, February 22, 1963.

77. JUNE, FRED C. 1/
The menhaden industry. In: Maurice E. Stansby (editor), Industrial Fishery Technology, chapter 11, p. 146-150. Reinhold Publishing Corporation, New York, 1963.

78. KANAYAMA, RICHARD K.
The use of alkalinity and conductivity measurements to estimate concentrations of 3-trifluormethyl-4-nitrophenol required for treating lamprey streams. Great Lakes Fishery Commission, Technical Report No. 7, 10 p., November 1963.

1/ Reprints not available.

79. KELLY, GEORGE F., AND ALLAN M. BARKER
Estimation of population size and mortality rates from tagged redfish, Sebastes marinus L., at Eastport, Maine. International Commission for the Northwest Atlantic Fisheries, North Atlantic Fish Marking Symposium, Woods Hole, Massachusetts, May 1961, Special Publication no. 4, p. 204-209, 1963.

80. _____
Effect of tagging on redfish growth rate at Eastport, Maine. International Commission for the Northwest Atlantic Fisheries, North Atlantic Fish Marking Symposium, Woods Hole, Massachusetts, May 1961, Special Publication no. 4, p. 210-213, 1963.

81. KENYON, KARL W., AND CLIFFORD H. FISCUS
Age determination in the Hawaiian monk seal. Journal of Mammalogy, vol. 44, no. 2, p. 280-282, May 20, 1963.

82. KEYES, MARK C.
Necrotic hemorrhagic enteritis in a seal. Small Animal Clinician, vol. 3, no. 11, p. 627, November 1963.

83. KIMSEY, J. BRUCE
Review of "Tropical Inland Fisheries," by C. F. Hickling. Transactions of the American Fisheries Society, vol. 92, no. 3, p. 323, July 1963.

84. _____
Review of "Between Pacific Tides," by Edward F. Ricketts and Jack Calvin. Third edition revised by Joel W. Hedgpeth. Transactions of the American Fisheries Society, vol. 92, no. 1, p. 69, January 1963.

85. KRAUEL, KATHRYN K., AND GEORGE J. RIDGWAY
Immunoelectrophoretic studies of red salmon (Oncorhynchus nerka) serum. International Archives of Allergy, vol. 23, p. 246-253, 1963.

86. KUIKUHN, JOSEPH H.
Review of "Fisheries Hydrography," by Ilmo Hela and Taivo Laevastu. Transactions of the American Fisheries Society, vol. 92, no. 2, p. 187-188, April 1963.

87. _____
Expanded research on Gulf of Mexico shrimp resources. Proceedings of the Gulf and Caribbean Fisheries Institute, Fifteenth Annual Session, November 1962, p. 65-78, June 1963.

88. LALANNE, JOHN
Chum salmon studies. International North Pacific Fisheries Commission Annual Report 1961, p. 119-124, 1963.

89. LANDER, ROBERT H.
Girth-length relationships in sockeye and chum salmon. Transactions of the American Fisheries Society, vol. 92, no. 3, p. 305-307, July 1963.

90. LANDRUM, B. J., AND T. DARK
Morphological classification of 1960 red salmon. International North Pacific Fisheries Commission Annual Report 1961, p. 108-114, 1963.

91. LASKER, REUBEN
The effect of temperature on the incubation time, development and growth of Pacific sardine (Sardinops caerulea Girard) and northern anchovy (Engraulis mordax Girard) embryos and larvae. (Abstract) Proceedings of the Sixteenth International Congress of Zoology, vol. 1, p. 114, 1963.

92. LOOSANOFF, VICTOR L.
Propagation of the common starfish, Asterias forbesi, in Long Island Sound during a twenty-five year period. (Abstract) Proceedings of the Sixteenth International Congress of Zoology, p. 98, August 20-27, 1963.

93. _____, AND HARRY C. DAVIS
Rearing of bivalve mollusk. In: Advances in Marine Biology, by F. S. Russell, vol. 1, 136 p., July 1963.

94. MC DERMOTT, JOHN P., AND ROBERT LIVINGSTONE, JR.
Haddock tag returns in relation to fish condition. International Commission for the Northwest Atlantic Fisheries, North Atlantic Fish Marking Symposium, Woods Hole, Massachusetts, May 1961, Special Publication no. 4, p. 216-217, 1963.

95. MC HUGH, J. L.
Conflict of interest and the Federal scientist. Non-official expression in writing, lecturing and teaching. Proceedings of the First Symposium on Current Problems in the Management of Scientific Personnel, Federal Council for Science and Technology, Washington, D. C., p. 105-108, 1963.

96. MC KERNAN, DONALD L., AND J. L. MC HUGH
Bureau of Commercial Fisheries. American Institute of Biological Science Bulletin, vol. 13, no. 5, p. 31-33, October 1963.

97. MC KERNAN, DONALD L., AND THE STAFF OF THE BUREAU
United States Department of Interior, The Bureau of Commercial Fisheries. American Zoologist, vol. 3, no. 3, p. 361-386, August 1963.

98. MC NEIL, WILLIAM J.
Quality of the spawning bed as it relates to survival and growth of pink salmon embryos and alevins and time of fry emergence. (Abstract) Proceedings of the Sixteenth International Congress of Zoology, vol. 1, p. 242, 1963.

99. _____
Status of research on the improvement of salmon spawning beds in Alaska. (Abstract) Report of Second Governor's Conference on Pacific Salmon, convened by Governor Albert D. Rosellini of Washington, Hyatt House, Seattle, January 7-10, p. 111, 1963.

100. MAGNUSON, JOHN J.
Tuna behavior and physiology, a review. Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species, FAO Fisheries Reports No. 6, vol. 3, p. 1057-1066, 1963.

101. _____, AND LLOYD L. SMITH 1/
Some phases of the life history of the trout-perch. Ecology, vol. 44, no. 1, p. 83-95, 1963.

102. MARR, JOHN C.
Subpopulation identification. Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species, FAO Fisheries Reports No. 6, vol. 3, p. 1011-1021, 1963.

103. _____
Note on the return rate of tagged skipjack, Katsuwonus pelamis, and the effects of handling. International Commission for the Northwest Atlantic Fisheries, North Atlantic Fish Marking Symposium, Woods Hole, Massachusetts, May 1961, Special Publication no. 4, p. 15-16, 1963.

104. _____
A model of the population biology of the Pacific sardine, Sardinops caerulea. Conseil Permanent International pour l' Exploration de la Mer, Rapports et Proceedings - Verbaux des Reunion, vol. 154, p. 270-278, 1963.

105. _____, AND LUCIAN M. SPRAGUE
The use of blood group characteristics in studying subpopulations of fishes. International Commission for the Northwest Atlantic Fisheries, North Atlantic Fish Marking Symposium, Woods Hole, Massachusetts, May 1961, Special Publication no. 4, p. 308-313, 1963.

1/ Reprints not available.

106. MARSHALL, J. S., AND A. M. BEETON
Influence of mineral composition of natural waters on strontium accumulation and discrimination by freshwater phytoplankton. (Abstract) Proceedings of Sixth Conference on Great Lakes Research, p. 266, 1963.

107. MATSUMOTO, WALTER M.
Unique shape of the first elongate haemal spine of albacore, Thunnus alalunga (Bonnaterre). Copeia, no. 2, p. 460-462, June 1963.

108. MERRELL, THEODORE R., JR.
Sea lions create havoc. Pacific Fisherman, vol. 61, no. 12, p. 13 and 15, November 1963.

109. MERRILL, ARTHUR S.
Mollusks from a buoy off Georgia. Nautilus, vol. 77, no. 2, p. 68-70, 1963.

110. _____, AND RUTH D. TURNER
Nest building in the bivalve genera, Musculus and Lima. The Veliger, vol. 6, no. 2, p. 55-59, October 1963.

111. MILLER, DAVID, JOHN B. COLTON, JR., AND ROBERT R. MARAK
A study of the vertical distribution of larval haddock. Journal du Conseil, International pour l' Exploration de la Mer, vol. 28, no. 1, p. 3-49, August 1963.

112. MOSHER, KENNETH H.
Racial analysis of red salmon by means of scales. International North Pacific Fisheries Commission, Document 395, Bulletin No. 11, p. 31-56, 1963.

113. O'CONNELL, CHARLES P.
The structure of the eye of Sardinops caerulea, Engraulis mordax, and four other pelagic marine teleosts. Journal of Morphology, vol. 113, no. 2, p. 287-329, September 1963.

114. OWEN, R. W., JR.
Trailing incubator for studies of C^{14} uptake by phytoplankton. Limnology and Oceanography, vol. 8, no. 2, p. 297-298, April 1963.

115. PEARSON, ROGER E.
Pink salmon studies. International North Pacific Fisheries Commission Annual Report 1961, p. 116-119, 1963.

116. PERKINS, HERBERT C.
Redescription and second known record of the bothid fish, Monolene asaedai Clark. Copeia, no. 2, p. 292-295, June 14, 1963.

117. POSGAY, J. A.
Tagging as a technique in population studies of the sea scallop. International Commission for the Northwest Atlantic Fisheries, North Atlantic Fish Marking Symposium, Woods Hole, Massachusetts, May 1961, Special Publication no. 4, p. 268-271, 1963.

118. PYCHA, RICHARD L. 1/
Great Lakes trout program showed progress last year. Fish Boat, vol. 8, no. 9, p. 32-35, 1963.

119. REES, GEORGE H.
Progress on blue crab research in the South Atlantic. Proceedings of the Gulf and Caribbean Fisheries Institute, Fifteenth Annual Session, November 1962, p. 110-115, June 1963.

120. REINTJES, JOHN W.
An initial inquiry into a photoelectric device to detect menhaden marked with flourescent pigments. International Commission for the Northwest Atlantic Fisheries, North Atlantic Fish Marking Symposium, Woods Hole, Massachusetts, May 1961, Special Publication no. 4, p. 362-368, 1963.

121. RENFRO, WILLIAM C.
Gas-bubble mortality of fishes in Galveston Bay, Texas. Transactions of the American Fisheries Society, vol. 92, no. 3, p. 320-322, July 1963.

122. RICE, DALE W.
Birds associating with elephants and hippopotamuses. The Auk, vol. 80, no. 2, p. 196-197, April 1963.

123. _____
Pacific coast whaling and whale research. Transactions of the Twenty-Eighth North American Wildlife and Natural Resources Conference, March 4, 5, and 6, 1963, p. 327-335, 1963.

124. _____
The whale marking cruise of the Sioux City off California and Baja, California. Norwegian Whaling Gazette, no. 6, 8 p., 1963.

1/ Reprints not available.

125. RICE, DALE W.
Progress report on biological studies of the larger cetacea in the waters off California. Norwegian Whaling Gazette, no. 7, p. 181-187, 1963.

126. RICE, THEODORE R.
Accumulation of radionuclides by aquatic organisms. In: "Studies of the Fate of Certain Radionuclides in Estuarine and Other Aquatic Environments," Public Health Service Publication No. 999-R-3, p. 35-50, 1963.

127. _____
The role of phytoplankton in the cycling of radionuclides in the marine environment. Proceedings of the First National Symposium on Radioecology, 1961, edited by Vincent Schultz and Alfred W. Klement, Jr., Reinhold Publication Corporation, New York and the American Institute of Biological Sciences, Washington, D. C., p. 179-185, 1963.

128. _____
Review of zinc in ecology. Proceedings of the First National Symposium on Radioecology, 1961, edited by Vincent Schultz and Alfred W. Klement, Jr., Reinhold Publishing Corporation, New York, and the American Institute of Biological Sciences, Washington, D. C., p. 619-631, 1963.

129. RIDGWAY, GEORGE J., AND FRED M. UTTER
Salmon serology. International North Pacific Fisheries Commission Annual Report 1961, p. 106-108, 1963.

130. ROBERTSON, ROBERT, AND ARTHUR S. MERRILL
Abnormal dextral hyperstrophy of post-larval Heliacus (Gastropoda: Architeconicidae). The Veliger, vol. 6, no. 2, p. 76-79, October 1963.

131. ROCKWELL, JULIUS, JR.
Overview of Government-Industry Oceanographic Instrumentation Symposium. Proceedings of the Mountain States Navy Research and Development Clinic, Raton, New Mexico, September 28-29, 1961, Communications and Electronics Foundation, C-1-C-6, 1963.

132. ROITHMAYR, CHARLES M., AND RICHARD A. WALLER
Seasonal occurrence of Brevoortia patronus in the northern Gulf of Mexico. Transactions of the American Fisheries Society, vol. 92, no. 3, p. 301-302, July 1963.

133. ROPES, JOHN W.
The incidence of Malacobdella grossa in hard clams from Nantucket Sound, Massachusetts. Limnology and Oceanography, vol. 8, no. 3, p. 353-355, July 1963.

134. ROSE, JOSEPH H.
Supposed larva of Protanyderus vipio (Osten Sacken) discovered in California. The Pan-Pacific Entomologist, vol. 39, no. 4, p. 270-272, October 1963.

Volume III

135. ROTHSCHILD, BRIAN J.
A critique of the scale method for determining the age of the alewife, Alosa pseudoharengus (Wilson). Transactions of the American Fisheries Society, vol. 92, no. 4, p. 409-413, October 1963.

136. _____
Graphic comparisons of meristic data. Copeia, no. 4, p. 601-603, December 1963.

137. ROUNSEFELL, GEORGE A.
Review of "Pink salmon (Oncorhynchus gorbuscha) in northern Norway in the year 1960," by Magnus Berg. Transactions of the American Fisheries Society, vol. 92, no. 2, p. 187, April 1963.

138. SABO, JULIUS J., JOHN P. BAPTIST AND FRED G. RUETER
Savannah estuary environmental radiological survey (SEERS) project. In: "Studies of the Fate of Certain Radionuclides in Estuarine and Other Aquatic Environments," Public Health Service Publication No. 999-R-3, p. 11-33, May 1963.

139. SALOMAN, CARL H., AND GORDON R. RINCKEY
Large lookdowns from Tampa Bay, Florida. Quarterly Journal of the Florida Academy of Sciences, vol. 26, no. 2, p. 192-193, June 1963.

140. SAUR, J. F. T.
A study of the quality of sea-water temperatures reported in logs of ships' weather observations. Journal of Applied Meteorology, vol. 2, no. 3, p. 417-425, June 1963.

141. SCHEFFER, VICTOR B., AND KARL W. KENYON
Elephant seal in Puget Sound, Washington. The Murrelet, vol. 44, no. 2, p. 23-24, 1963.

142. _____, _____
Baculum size in pinnipeds. Zeitschrift fur Saugetierkunde, vol. 28, no. 1, p. 38-41, 1963.

143. SECKEL, GUNTER R.
Climatic parameters and the Hawaiian skipjack fishery. Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species, FAO Fisheries Reports No. 6, vol. 3, p. 1201-1208, 1963.

144. SHAW, WILLIAM N.
Index of condition and percent solids of raft-grown oysters in Massachusetts. Proceedings of the National Shellfisheries Association for 1961, vol. 52, p. 47-52, June 1963.

145. _____
A method of tagging channeled whelks. Nautilus, vol. 77, no. 1, p. 28-30, July 1963.

146. SHERMAN, KENNETH
Pontellid copepod distribution in relation to surface water types in the central north Pacific. Limnology and Oceanography, vol. 8, no. 2, p. 214-227, April 1963.

147. SHIPPEN, HERBERT AND TAKASHI MIYAHARA
King crab studies. International North Pacific Fisheries Commission Annual Report 1961, p. 124-127, 1963.

148. SHOMURA, RICHARD S.
Monofilament gill net fishing for skipjack tuna in Hawaiian waters (a progress report). Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species, FAO Fisheries Reports No. 6, vol. 3, p. 1177-1199, 1963.

149. _____, AND BETTY ANN KEALA
Growth and sexual dimorphism in growth of bigeye tuna (Thunnus obesus), a preliminary report. Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species, FAO Fisheries Reports No. 6, vol. 3, p. 1409-1417, 1963.

150. SHUMWAY, GEORGE AND THOMAS E. CHASE
Bathymetry in the Galapagos Region. Presented at the 10th Pacific Science Congress of the Pacific Science Association, held at the University of Hawaii, Honolulu, Hawaii, USA, August 21-September 6, 1961, p. 11-19, 1963.

151. SINDERMANN, CARL J.
Disease in marine populations. Transactions of the Twenty-Eighth North American Wildlife and Natural Resources Conference, March 4, 5, and 6, 1963, p. 336-356, 1963.

152. _____
Immunogenetic studies of elasmobranch fishes. (Abstract) Proceedings of the Sixteenth International Congress of Zoology, vol. 2, p. 210, 1963.

153. _____, AND KENNETH A HONEY
Electrophoretic analysis of the hemoglobins of Atlantic clupeoid fishes. Copeia, no. 3, p. 534-537, September 1963.

154. SKUD, BERNARD E.
Initial sardine biology research results termed very informative. Portland Press Herald, vol. 102, no. 6, 2 p., June 1963.

155. SMOKER, WILLIAM A.
Influence of freshwater environment on survival of Coho salmon. (Abstract) Proceedings of the Sixteenth International Congress of Zoology, vol. 1, p. 245, 1963.

156. SPRAGUE, LUCIAN M., JAMES R. HOLLOWAY, AND LESLIE I. NAKASHIMA
Studies of the erythrocyte antigens of albacore, bigeye, skipjack, and yellowfin tunas and their use in subpopulation identification. Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species, FAO Fisheries Reports No. 6, vol. 3, p. 1381-1393, 1963.

157. SPRINGER, STEWART
Field observations on large sharks of the Florida-Caribbean Region. In: Sharks and Survival, D. C. Health, Boston, p. 95-113, 1963.

158. _____, AND PERRY W. GILBERT
Anti-shark measures. In: Sharks and Survival, D. C. Health, Boston, p. 465-476, 1963.

159. _____, AND ROSEMARY H. LOWE
A new smooth dogshark, Mustelus higmani, from the equatorial Atlantic Coast of South America. Copeia, no. 2, p. 245-251, June 1963.

160. SPRINGER, VICTOR G., AND JOHN H. FINUCANE
The African cichlid, Tilapia heudeloti Dumer, in the commercial fish catch of Florida. Transactions of the American Fisheries Society, vol. 92, no. 3, p. 317-318, July 1963.

161. STICKNEY, ALDEN P.
Histology of the reproductive system of the soft-shell clam (Mya arenaria). Biological Bulletin, vol. 125, no. 2, p. 344-351, October 1963.

162. STRASBURG, DONALD W.
Employment of submarines for scientific research. Proceedings of the Hawaiian Academy of Science, Thirty-Eighth Annual Meeting 1962-63, published by the University of Hawaii, p. 13, 1963.

163. _____
The diet and dentition of Isistius brasiliensis, with remarks on tooth replacement in other sharks. Copeia, no. 1, p. 33-40, March 30, 1963.

164. THOMPSON, RICHARD B.
Chironomids and trout. Washington State Game Department, Game Bulletin, vol. 15, no. 2, p. 4-5, April, May, June 1963.

165. TREFETHEN, PARKER S.
Sonic fish tracking. International Commission for the Northwest Atlantic Fisheries, North Atlantic Fish Marking Symposium, Woods Hole, Massachusetts, May 1961, Special Publication no. 4, p. 81-83, 1963.

166. _____, AND A. J. NOVOTNY
Marking fingerling salmon with trace-elements and nonradioactive isotopes. International Commission for the Northwest Atlantic Fisheries, North Atlantic Fish Marking Symposium, Woods Hole, Massachusetts, May 1961, Special Publication no. 4, p. 64-65, 1963.

167. TUBIASH, HASKELL S., AND PAUL E. CHANLEY
Bacterial necrosis of bivalve larvae. (Abstract) Bacteriological Proceedings, vol. 63, p. 164, 1963.

168. UCHIDA, RICHARD N.
Synopsis of biological data on frigate mackerel Auxis thazard (Lacepede) 1802 (Pacific Ocean). Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species, FAO Fisheries Reports No. 6, vol. 2, p. 241-273, 1963.

169. UKELES, RAVENNA
The effect of surface active agents on the growth of marine phytoplankton. Journal of Protozoology, Program and Abstracts Supplement, vol. 10, p. 10, August 1963.

170. VAN LANDINGHAM, JOHN W.
Inorganic nutrients in the sea. Journal of Chemical Education, vol. 40, p. 272-276, 1963.

171. WALDRON, KENNETH D.
Synopsis of biological data on skipjack Katsuwonus pelamis (Linnaeus) 1758 (Pacific Ocean). Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species, FAO Fisheries Reports No. 6, vol. 2, p. 695-748, 1963.

172. _____, AND JOSEPH E. KING
Food of skipjack in the central Pacific. Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species, FAO Fisheries Reports No. 6, vol. 3, p. 1431-1457, 1963.

173. WELLS, LaRUE, AND ALFRED M. BEETON
Food of the bloater, Coregonus hoyi, in Lake Michigan. Transactions of the American Fisheries Society, vol. 92, no. 3, p. 245-255, July 1963.

174. WIGLEY, ROLAND L.
Occurrence of Praunus flexuosus (O.F. Muller) (Mysidacea) in New England waters. Crustacena, vol. 6, part 2, 1 p., 1963.

175. _____
Pogonophora on the New England continental slope. Science, vol. 141, no. 3578, p. 358-359, July 26, 1963.

176. WILIMOVSKY, NORMAN J.
A radioactive internal tag for herring. International Commission for the Northwest Atlantic Fisheries, North Atlantic Fish Marking Symposium, Woods Hole, Massachusetts, May 1961, Special Publication no. 4, p. 359-361, 1963.

177. WILSON, ROBERT C.
Fishery oceanography in the tropical Atlantic. Transactions of the Twenty-Seventh North American Wildlife and Natural Resources Conference, March 12, 13, and 14, 1962, p. 351-361, February 1963.

178. WISE, JOHN P.
Factors affecting number and quality of returns from tagging cod with different tags and using different methods of capture in ICNAF Division 4 X and 5 Y in 1957. International Commission for the Northwest Atlantic Fisheries, North Atlantic Fish Marking Symposium, Woods Hole, Massachusetts, May 1961, Special Publication no. 4, p. 101-105, 1963.

179. WOLF, ROBERT S., AND ANITA E. DAUGHERTY
Age and length composition of the sardine catch off the Pacific Coast of the United States and Mexico in 1960-61. California Fish and Game, vol. 49, no. 4, p. 290-301, October 1963.

180. WOLFERT, DAVID R.
The movements of walleyes tagged as yearlings in Lake Erie. Transactions of the American Fisheries Society, vol. 92, no. 4, p. 414-420, October 1963.

181. YOSHIDA, HOWARD O., AND TAMIO OTSU
Synopsis of biological data on albacore Thunnus germo (Lacepede) 1800 (Pacific and Indian Oceans). Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species, FAO Fisheries Reports No. 6, vol. 2, p. 274-318, 1963.

182. YUEN, HEENY S. H.
Schooling behavior within aggregations composed of yellowfin and skipjack tuna. Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species, FAO Fisheries Reports No. 6, vol. 3, p. 1419-1429, 1963.

183. ZEIN-ELDIN, ZOULA P.
Effect of salinity on growth of postlarval penaeid shrimp. Biological Bulletin, vol. 125, no. 1, p. 188-196, August 1963.

REPRINTS OF CONTRACTORS APPEARING IN OTHER THAN FISH AND WILDLIFE SERVICE PUBLICATIONS

184. AYERS, ROBERT J., AND JAMES M. MEEHAN
Catch locality, fishing effort, and length-frequency data for albacore tuna landed in Oregon, 1951-60. Fish Commission of Oregon, Investigational Report No. 2, 180 p., August 1963.

185. BLACKBURN, MAURICE
Distribution and abundance of tuna related to wind and ocean conditions in the Gulf of Tehuantepee, Mexico. Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species, FAO Fisheries Reports No. 6, vol. 3, p. 1557-1584, 1963.

186. _____ 1/
Unmanned moored station systems for oceanography and meteorology. Transactions of the American Geophysical Union, vol. 44, no. 2, p. 595-598, 1963.

187. GRIFFITHS, RAYMOND C.
Studies of oceanic fronts in the mouth of the Gulf of California, an area of tuna migrations. Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species, FAO Fisheries Reports No. 6, vol. 3, p. 1583-1609, 1963.

188. HARTT, ALLAN C.
Problems in tagging salmon at sea. International Commission for the Northwest Atlantic Fisheries, North Atlantic Fish Marking Symposium, Woods Hole, Massachusetts, May 1961, Special Publication no. 4, p. 144-145, 1963.

189. _____
Tagging studies. International North Pacific Fisheries Commission Annual Report 1961, p. 83-91, 1963.

190. HOLMES, R. W. 1/
A summary of productivity measurements in the southeastern Pacific Ocean. Proceedings of the Conference on Primary Productivity Measurements Marine and Freshwater, held at the University of Hawaii, August 21-September 6, 1961. U.S. Atomic Energy Commission, TID 7633, p. 18-57, 1963.

1/ Reprints not available.

191. RODEN, GUNNAR I.
On sea level temperature and salinity variations in the central tropical Pacific and Pacific Ocean islands. Journal of Geophysical Research, vol. 68, no. 2, p. 455-472, 1963.

192. SCHWARTZ, N., H. E. GAFFNEY, M. S. SCHMUTZER, AND F. D. STEFANO
A method for the analysis of chlorinated benzenes in clams (Mercenaria mercenaria) and oysters (Crassostrea virginica). Journal of the Association of Official Agricultural Chemists, vol. 46, no. 5, p. 893-898, 1963.

193. SPARKS, ALBERT K.
Infection of Crassostrea virginica (Gmelin) from Hawaii with a larval tapeworm, Tylocephalum. Journal of Insect Pathology, vol. 5, no. 3, p. 284-288, 1963.

194. THOMAS, WILLIAM H.
Physiological factors affecting the interpretation of phytoplankton production measurements. Proceedings of the Conference on Primary Productivity Measurements, Marine and Freshwater, Atomic Energy Commission, TID 7633, p. 147-162, 1963.

195. _____, HAROLD L. SCOTTEN, AND JOHN S. BRADSHAW
Thermal gradient incubators for small aquatic organisms. Limnology and Oceanography, vol. 8, no. 3, p. 357-360, 1963.

196. WOOSTER, W. S., AND J. L. REID 1/
Eastern boundary currents. In: M. N. Hill (general editor) The Sea: Ideas and Observations on Progress in the Study of the Seas. Interscience Publishers, New York and London, vol. 2, p. 253-280, 1963.

197. WYRTKI, KLAUS
The horizontal and vertical field of motion in the Peru current. Bulletin of Scripps Institution of Oceanography, University of California, La Jolla, California, vol. 8, no. 4, p. 313-346, 1963.

198. _____, AND EDWARD B. BENNETT
Vertical eddy viscosity in the Pacific equatorial undercurrent. Deep-Sea Research, vol. 10, p. 449-455, 1963.

1/ Reprints not available.

PAPERS PUBLISHED IN 1962, 1961, AND 1960 NOT INCLUDED IN THE VOLUME OF COLLECTED REPRINTS

1962

199. MOFFETT, JAMES W. 1/
An instance of upwelling along the east shore of Lake Michigan, 1955, Great Lakes Research Institute of Science and Technology, The University of Michigan, Publication No. 9, p. 126, 1962.

1961

200. LEWIS, DONALD E. 1/
Red salmon (*Oncorhynchus nerka*) without dorsal fin. Copeia, no. 1, p. 116-117, 1961.

1960

201. EDWARDS, ROBERT L. 1/
A new Austromenopen (Menoponidae-Mallophaga) parasitizing shearwaters (Puffinus-Procelliariformes). The Canadian Entomologist, vol. 92, no. 11, p. 817-819, November 1960.

1/ Reprints not available.

LIST OF
REPORTS OF THE DIVISION OF BIOLOGICAL RESEARCH
APPEARING IN PUBLICATIONS OF THE FISH AND WILDLIFE SERVICE - 1963

CIRCULARS

1. BAKER, RALPH C., FORD WILKE, AND C. HOWARD BALTZO
The northern fur seal. U.S. Fish and Wildlife Service, Circular 169, iii + 19 p., September 1963.

2. BUREAU OF COMMERCIAL FISHERIES BIOLOGICAL LABORATORY, BEAUFORT, NORTH CAROLINA
Annual report ending June 30, 1961. U.S. Fish and Wildlife Service, Circular 148, iii + 40 p., 1963.

3. BUREAU OF COMMERCIAL FISHERIES BIOLOGICAL LABORATORY, GALVESTON, TEXAS
Biological Laboratory, Galveston, Texas, fishery research for the year ending June 30, 1962. U.S. Fish and Wildlife Service, Circular 161, iii + 101 p., 1963.

4. BUREAU OF COMMERCIAL FISHERIES BIOLOGICAL LABORATORY, HONOLULU, HAWAII
Progress in 1961-62. U.S. Fish and Wildlife Service, Circular 163, 35 p., February 1963.

5. BUREAU OF COMMERCIAL FISHERIES, BIOLOGICAL LABORATORY AT HONOLULU, SAN DIEGO AND STANFORD
Skipjack - a world resource. U.S. Fish and Wildlife Service, Circular 165, i + 28 p., May 1963.

6. HANKS, ROBERT W.
The soft-shell clam. U.S. Fish and Wildlife Service, Circular 162, i + 16 p., December 1963.

7. ROUNSEFELL, GEORGE A.
Bureau of Commercial Fisheries Biological Laboratory, Galveston, Texas. U.S. Fish and Wildlife S rvice, Circular 154, i + 29 p., November 1963.

8. SHOMURA, RICHARD S.
Monofilament gill net fishing for skipjack tuna in Hawaiian waters, 1961-62. U.S. Fish and Wildlife Service, Circular 170, iii + 21 p., 1963.

9. STEARNS, FRANKLIN
Inventory of oceanographic data for the western north Atlantic Ocean and the Gulf of Mexico. (Oceanographic station data, bathythermograph observations and sea-surface temperature observations.) U.S. Fish and Wildlife Service, Circular 176, iii + 39 p., December 1963.

COMMERCIAL FISHERIES REVIEW

1. FLITTNER, GLENN A.
Review of the 1962 seasonal movement of albacore tuna off the Pacific Coast of the U.S. U.S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 25, no. 4, p. 7-13, April 1963. (Also as Separate No. 674).

2. FRENCH, ROBERT R.
Activation of U.S. Bureau of Commercial Fisheries Research Vessel George B. Kelez. U.S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 25, no. 8, p. 6-13, August 1963. (Also as Separate No. 684)

3. JENSEN, ALBERT C., AND ROBERT K. BRIGHAM
The line-trawl fishery for cod and haddock at Chatham, Massachusetts. U.S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 25, no. 6, p. 14-19, June 1963. (Also as Separate No. 679)

4. LARKINS, HERBERT A.
Comparison of salmon catches in monofilament and multifilament gill nets. U.S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 25, no. 6, p. 1-11, May 1963. (Also as Separate No. 675)

5. LOOSANOFF, VICTOR L., AND HARRY C. DAVIS
Shellfish hatcheries and their future. U.S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 25, no. 1, p. 1-11, January 1963. (Also as Separate No. 664)

6. ROCKWELL, JULIUS, JR.
An electromechanical fishing and counting fence used in Ireland. U.S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 25, no. 12, p. 1-6, December 1963. (Also as Separate No. 695)

FISHERY BULLETINS

1. BAILEY, MERRYLL M.
Age, growth, and maturity of round whitefish of the Apostle Islands and Isle Royale regions, Lake Superior. U.S. Fish and Wildlife Service, Fishery Bulletin, vol. 63, no. 1, p. 63-75, 1963.

2. COLLINS, GERALD B., CARL H. ELLING, JOSEPH R. GAULEY, AND CLARK S. THOMPSON
Effect of fishway slope on performance and biochemistry of salmonids. U.S. Fish and Wildlife Service, Fishery Bulletin, vol. 63, no. 1, p. 221-253, 1963.

3. DRYER, WILLIAM R.
Age and growth of whitefish in Lake Superior. U.S. Fish and Wildlife Service, Fishery Bulletin, vol. 63, no. 1, p. 77-95, 1963.

4. GANGMARK, HAROLD A., AND F. BRUCE SANFORD
Theory on development of mounds near Red Bluff, California. U.S. Fish and Wildlife Service, Fishery Bulletin, vol. 63, no. 1, p. 213-220, 1963.

5. GAULEY, JOSEPH R., AND CLARK S. THOMPSON
Further studies on fishway slope and its effect on rate of passage of salmonids. U.S. Fish and Wildlife Service, Fishery Bulletin, vol. 63, no. 1, p. 45-62, 1963.

6. LUX, FRED E.
Identification of New England yellowtail flounder groups. U.S. Fish and Wildlife Service, Fishery Bulletin, vol. 63, no. 1, p. 1-10, 1963.

7. MONAN, GERALD E.
Development of a mathematical relationship between electric-field parameters and the electrical characteristics of fish. U.S. Fish and Wildlife Service, Fishery Bulletin, vol. 63, no. 1, p. 123-136, 1963.

8. NICHOLS, PAUL R., AND WILLIAM H. MASSMANN
Abundance, age, and fecundity of shad, York River, Virginia, 1953-59. U.S. Fish and Wildlife Service, Fishery Bulletin, vol. 63, no. 1, p. 179-187, 1963.

9. OTSU, TAMIO, AND RICHARD N. UCHIDA
Model of the migration of albacore in the North Pacific Ocean. U.S. Fish and Wildlife Service, Fishery Bulletin, vol. 63, no. 1, p. 33-44, 1963.

10. POWERS, CHARLES F.
Some aspects of the oceanography of Little Port Walter estuary, Baranof Island, Alaska. U.S. Fish and Wildlife Service, Fishery Bulletin, vol. 63, no. 1, p. 143-164, 1963.

11. RENFRO, WILLIAM C., AND HARRY L. COOK
Early larval stages of the seabob, Xiphopeneus kroyeri (Heller). U.S. Fish and Wildlife Service, Fishery Bulletin, vol. 63, no. 1, p. 165-177, 1963.

12. RIDGWAY, GEORGE J.
Distinguishing tuna species by immunochemical methods. U.S. Fish and Wildlife Service, Fishery Bulletin, vol. 63, no. 1, p. 205-211, 1963.

13. SHAW, WILLIAM N., AND JAMES A. MC CANN
Comparisons of growth of four strains of oysters raised in Taylors Pond, Chatham, Massachusetts. U.S. Fish and Wildlife Service, Fishery Bulletin, vol. 63, no. 1, p. 11-17, 1963.

14. SINDERMANN, CARL
Use of plant hemagglutinins in serological studies of clupeoid fishes. U.S. Fish and Wildlife Service, Fishery Bulletin, vol. 63, no. 1, p. 137-141, 1963.

15. SKUD, BERNARD E.
Herring tagging experiments in southeastern Alaska. U.S. Fish and Wildlife Service, Fishery Bulletin, vol. 63, no. 1, p. 19-32, 1963.

16. WEAVER, CHARLES R.
Influence of water velocity upon orientation and performance of adult migrating salmonids. U.S. Fish and Wildlife Service, Fishery Bulletin, vol. 63, no. 1, p. 97-121, 1963.

17. WISE, JOHN P.
Bibliography on the biology of the cod, Gadus morhua and related species. U.S. Fish and Wildlife Service, Fishery Bulletin 215, vol. 62, p. 483-538, 1963.

18. WISE, JOHN P.
Cod groups in the New England area. U.S. Fish and Wildlife Service, Fishery Bulletin, vol. 63, no. 1, p. 189-203, 1963.

FISHERY LEAFLETS

1. ALLEN, DONALD M.
Shrimp farming. U.S. Fish and Wildlife Service, Fishery Leaflet 551, 8 p., October 1963.

2. REES, GEORGE H.
Edible crabs of the United States. U.S. Fish and Wildlife Service, Fishery Leaflet 550, 18 p., December 1963.

3. ROUNSEFELL, GEORGE A.
Marking fish and invertebrates. U.S. Fish and Wildlife Service, Fishery Leaflet 549, iii + 12 p., 1963.

PROGRESSIVE FISH-CULTURIST

1. BLAHM, THEODORE H.
   A detector of fish activity. U.S. Fish and Wildlife Service, Progressive Fish-Culturist, vol. 25, no. 1, p. 54-55, 1963.

2. BONNER, RUPERT R.
   A method of transporting striped bass. U.S. Fish and Wildlife Service, Progressive Fish-Culturist, vol. 25, no. 4, p. 206-217, October 1963.

3. CLAUSING, DOUGLAS S.
   Improved gummed paper for plastic scale impressions. U.S. Fish and Wildlife Service, Progressive Fish-Culturist, vol. 25, no. 2, p. 100, April 1963.

4. MONAN, GERALD E.
   A device for measuring the length of fish. U.S. Fish and Wildlife Service, Progressive Fish-Culturist, vol. 25, no. 2, p. 107-108, April 1963.

5. NEWMAN, H. WILLIAM

   Biopsy cannula for tissue samples from live adult fish. U.S. Fish and Wildlife Service, Progressive Fish-Culturist, vol. 25, no. 3, p. 162-163, July 1963.

6. PERKINS, FRANK E.
   A gravity food dispenser for laboratory fish. U.S. Fish and Wildlife Service, Progressive Fish-Culturist, vol. 25, no. 1, p. 56, January 1963.

7. RODMAN, DUANE T.
   Anesthetizing and air-transporting young white sturgeons. U.S. Fish and Wildlife Service, Progressive Fish-Culturist, vol. 25, no. 2, p. 71-78, April 1963.

8. ROTHSCHILD, BRIAN J.
   A utility raft for fishery work. U.S. Fish and Wildlife Service, Progressive Fish-Culturist, vol. 25, no. 4, p. 218-219, October 1963.

9. WHEELER, CHESTER O.
   Solenoid release for remote operations. U.S. Fish and Wildlife Service, Progressive Fish-Culturist, vol. 25, no. 4, p. 215-216, October 1963.

SPECIAL SCIENTIFIC REPORT--FISHERIES

1. DAY, C. GODFREY 2/
   Oceanographic observations, 1960 East Coast of the United States. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 406, iii + 59 p., 1963.

2. DRAGOVICH, ALEXANDER, JOHN H. FINUCANE, JOHN A. KELLY, JR., AND BILLIE Z. MAY
   Counts of red-tide organisms, Gymnodium breve, and associated oceanographic data from Florida west coast, 1960-61. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 455, iii + 40 p., October 1963.

3. HAYES, MURRAY L., AND DONALD T. MONTGOMERY
   Movements of king crabs tagged and released in Shumagin Islands area 1957-62. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 458, ii + 7 p., December 1963.

4. HESTER, FRANK J., DONALD C. AASTED, AND ROBERT W. GILKEY
   The bathkymograph, a depth-time record. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 44, iii + 5 p., February 1963.

5. HICKS, STEACY D. 2/
   Physical oceanographic studies of Narragansett Bay 1957 and 1958. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 457, iii + 30 p., September 1963.

6. KRAMER, DAVID
   Records and observations from plankton grid studies off Baja California, April 1952. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 422, iii + 42 p., September 1963.

7. MC CANN, JAMES A., AND FRANK A. DREYER
   Length and age frequency samples collected from Georges Bank haddock landings, 1931-55. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 438, iv + 127 p., 1963.

8. _____ _____
   Length and age frequency samples collected from Georges Bank and Gulf of Maine haddock landings, 1956-60. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 439, iii + 113 p., 1963.

2/ Contract paper.

9. MC LAUGHLIN, PATSY A.
Survey of the benthic invertebrate fauna of the eastern Bering Sea. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 401, iii + 75 p., 1963.

10. MATHISEN, OLE A., AND RON J. LOPP 2/
Photographic census of the steller sea lion herds in Alaska, 1956-58. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 424, iii + 20 p., 1963.

11. _____, ROBERT L. BURGNER, AND TED S. Y. KOO 2/
Statistical records and computations on red salmon (Oncorhynchus nerka) runs in the Nushagak District, Bristol Bay, Alaska, 1946-59. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 468, 32 p., June 1963.

12. NICHOLS, PAUL R., AND PEGGY M. KENEY
Crab larvae (Callinectes), in plankton collections from cruises of M/V Theodore N. Gill, South Atlantic Coast of the United States, 1953-54. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 448, ii + 14 p., October 1963.

13. O'CONNELL, CHARLES P., AND RODERICK J. H. LEONG
A towed pump and shipboard filtering system for sampling small zooplankters. U.S. Fish and Wildlife Service Special Scientific Report--Fisheries No. 452, ii + 19 p., May 1963.

14. ORRELL, RUSSELL F., AND EDWARD KLINKHART 2/
Stream catalog of Southeastern Alaska Regulatory District No. 2. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 453, 185 p., April 1963.

15. _____, CARL ROSIER AND LYLE R. SIMPSON 2/
Stream catalog of Southeastern Alaska Regulatory Districts Nos. 3 and 4. U.S. Fish and Wildlife Service Special Scientific Report--Fisheries No. 465, ii + 237 p., August 1963.

16. OWEN, ROBERT W., JR.
Northeast Pacific albacore oceanography survey, 1961. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 44, iii + 35 p., November 1963.

17. PONTECORVO, GIULIO, AND LESLIE W. SCATTERGOOD
Economic survey of the U.S. fisheries in the Passamaquoddy region, 1956-57. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 473, iii, + 14 p., December 1963.

2/ Contract paper.

18. RALEIGH, ROBERT F.
The composition, abundance, and depth distribution of the 1957 summer net zooplankton of Bare Lake, Alaska, after fertilization. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 423, iii + 14 p., February 1963.

19. RENNER, JAMES A.
Sea surface temperature monthly average and anomaly charts, Eastern Tropical Pacific Ocean, 1947-1958. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 442, iii + 57 p., 1963.

20. ROITHMAYR, CHARLES M.
Distribution of fishing by purse seine vessels for Atlantic menhaden, 1955-59. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 434, iii + 22 p., 1963.

21. ROPPEL, ALTON Y., ANCEL M. JOHNSON, RICHARD D. BAUER, DOUGLAS G. CHAPMAN, AND FORD WILKE
Fur seal investigations Pribilof Islands, Alaska 1962. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 454, vi + 101 p., December 1963.

22. SCHEFFER, VICTOR B., AND DALE W. RICE
A list of the marine mammals of the world. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 431, i + 12 p., 1963.

23. SUTHERLAND, DOYLE F.
Variation in vertebral numbers of juvenile Atlantic menhaden. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 435, iii, 21 p., 1963.

24. THORSTEINSON, FREDRIK V., WALLACE H. NEREMBERG, AND HOWARD D. SMITH
The length, age, and sex ratio of chum salmon in the Alaska Peninsula, Kodiak Island, and Prince William Sounds areas of Alaska. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 430, 80 p., 1963.

25. THRAILKILL, JAMES R.
Zooplankton volumes off the Pacific coast, 1959. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 414, ii + 77 p., 1963.

26. VAN OOSTEN, JOHN
Surface currents of Lake Michigan, 1931 and 1932. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 413, iii + 51 p., 1963.

27. WATSON, JOHN E.
A method for tagging immature herring. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 451, iii + 7 p., August 1963.

28. YANCEY, ROBERT M., AND FREDRIK V. THORSTEINSON
The king salmon of Cook Inlet, Alaska. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 440 ii + 8 p., 1963.

espite the undoubted validity of many f the papers. Rather, it appears to have een to introduce the reader to the wealth f bird literature and to the bird enthuiasts, past and present, who have deeloped it. To this end, the compilers ave been successful. The collection hould provide considerable pleasant eading for anyone interested in skimming he surface of the bird world without elving too deeply into any one technical spect of ornithology.

Some of the more serious bird students vill be familiar with much of the literature ncluded. Few, however, will have read .ll or most of the accounts. My guess s that, although technical ornithologists nay doubt the value of this anthology on he grounds that it adds nothing new, nany general bird watchers and avid mateurs will find it a mine of interesting eading. It is a good book to have on he table for short periods of relaxation, ot a book to systematically further one's rnithological education.

One article from the *Atlantic Naturalist* s included: *Alexander Wilson, Father of American Ornithology,* by Mrs. Arthur A. Allen, from the November-December 1952 issue. *Fred H. Dale*

Dr. Dale is Research Biologist, Branch of Wildlife Research, U. S. Fish and Wildlife Service.

Slijper, E. J. WHALES. Basic Books. 1962. Pp. 475. Illus. $12.50.

Dr. E. J. Slijper, Professor of General Zoology at the University of Amsterdam, has devoted his life to the study of whales. In his book *Whales,* he has recorded the enormous advances made in whale biology, concentrating particularly on physiology, anatomy, and behaviour of whales.

Dr. Slijper produced a readable and enlightening history of whales through generous use of personal experiences of his own and from many of the authors whose works he cited. The authors' work is generally well documented, indicated by over 700 references. These are listed by chapter in the bibliography. His style lends itself to easy assimilation of facts about whales.

The author illustrates graphically the size of whales. Blue whales are the largest animals in the world, the record weight exceeding 135 tons; this was a female blue whale caught by a Japanese whaler in January 1948. This particular whale weighed more than 30 elephants, 200 cows, or 1600 men. A fore stomach measuring 6½ feet by 4¾ feet removed from a killer whale was found to contain 13 porpoises and 14 seals; a fifteenth seal was found in the animal's throat. This illustration has no reference cited so cannot be checked, but it is questionable that 27 whole animals the size of seals and porpoises could be received at one time by the fore stomach. Perhaps it would have been more accurate to say that the *remains* of these animals were found in the stomach.

The relationship between feeding problems of whales and reproduction is given importance with the author's explanation that every cetacean species has its own rate of fetal growth. He cites evidence that mating, lactation, and weaning often occur during periods of abundant food supply.

The first 13 chapters of Dr. Slijper's book deal with the basic biology of whales. Scientific facts concerning different species of whales are laid out for the reader in an unbiased and forthright manner. However, in the 14th chapter, "The Future of Whales and Whaling," the author seems to become suddenly defensive and disregards scientific approach to the study of whales which he demonstrated in his earlier chapters. He is naive in rationalizing whaling problems in the Antarctic.

The International Whaling Commission has recorded comprehensive data on whales. Until recently, only segments of these data were analyzed. Since completion of this book, the Commission has appointed a special scientific committee to analyze in depth, all collected data pertinent to population studies. This special committee will make known its findings to the Commission members early in 1963. The Commission will then use this information to establish regulation relevant to Antarctic whales, particularly blue whales and fin whales.

It is unfortunate that the author does not take a stronger stand regarding conservation of whales and control of the Antarctic whaling industry.

Carl E. Abegglen

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useful body of information on northern sea birds.

The book lacks a section on printing and translator's techniques. It is clear from examination that the printing method is photo offset but in the case of tables the techniques preliminary to printing are obscure. Close examination would seem to indicate that in some cases the tables were re-typed but that others were photographically reproduced from the original with English captions pasted over the Russian. I have examined some of the tables with an eye toward discovering possible numerical departures from the original and have discovered none. Since there are many large tables, it would be reassuring to know to what extent it is likely that errors have crept in from sheer mass of data to be transcribed.

The translated text is pedestrian and frequently awkward. Scientifically, of course, it is preferable that the translator not take too many liberties in the interest of smoothness. Often, however, the translated text is so awkward as to leave one in doubt of the exact meaning of phrases, particularly if the reader is not intimately familiar with the species in question. It appears from such cases of unclear meaning and from many cases like ". . .the nutritious value of berries. . ." (page 34) instead of ". . .the nutritive value of berries. . .", that early drafts were not carefully enough revised. Typographical errors are not excessive but there are some glaring slips, presumably from inattentive proofreading of the galleys. A good example is the omission of page numbers from a large part of the table of contents.

The photographs might well have been omitted. Of poor quality in the original, they are disastrous in the translation. Retouching is obvious in the original and, incredibly, additional retouching has been done in the translate version. Figure 135 on page 304 is particularly flagrant example of retouching in the translation.

The book will be much used by persons interested in the ecology of colonial sea birds. Though not aesthetically the best the printing method does have the virtue of economy. The wealth of information in the book plus its low price may well earn it a place on many bookshelves.

L. Gerard Swartz

Dr. Swartz is Associate Professor of Zoology at the University of Alaska.

A TREASURY OF BIRDLORE, edited by Joseph Wood Krutch and Paul S. Eriksson. Doubleday. 1962. Pp. 390. $7.50.

This anthology includes 83 articles that range from 1 to 14 pages in length and cover almost all aspects of birdlore. Most of the well known writers and students in this field are included, along with a few lesser lights.

The review of an anthology is not easy. One is tempted to comment on the style of the writers or their ideas; however, this is not a valid criterion for judging such a compilation. Rather, we should try to find out the purpose of the compilers in getting the book together and judge how well they have succeeded toward this end.

Certainly, the objective is not to provide systematic instruction in ornitholog

TROPICAL INLAND FISHERIES.

By C. F. Hickling. John Wiley & Sons, New York. $7.25. xvi + 287 pp. + 62 pl.; text ill. 1962.

Tropical inland fisheries around the world are still quite primitive, both with respect to fishing methods and methods of preserving the catch. They are carried out in a variety of habitats: rivers, flood-plains, swamps, shallow lakes, and deep lakes. These habitats range in condition from the impermanent but highly productive flood plains of rivers which are annually inundated during the rainy season to the all-too-permanent deep waters of lakes like Kivu and Nyasa in Africa, which are devoid of oxygen and fish.

The author details the changes which are rapidly taking place in the fisheries, including the increasing use of modern fishing gear such as gill nets made of synthetic fibers, the use of outboard motors on canoes, and the development of modern processing plants, especially on the larger African lakes.

Some of the most productive fisheries are in the flood plains. An outstanding example is the flood plain associated with the annual overflow of the Mekong River of Cambodia into the Grand Lac. This flood fishery yields an annual catch of about 100,000 metric tons. Another important flood fishery is that of the Middle Niger, which has an annual yield of approximately 45,000 metric tons. This latter fishery may soon become a victim of progress: the equatorial Nile project plans to save a large part of the water at present lost by the spilling of the upper Nile over its flood-plain.

The development of fisheries in the large African lakes is as much dependent on development of adequate roads for transport of fish to new markets as on improvement of fishing methods. The author mentions in his discussion of Lake Nyasa that, with rare exceptions, fresh fish is not available to Africans living more than about 3 miles from the lake shore. An interesting comparison of the relative effectiveness of primitive versus modern fishing gear is given for the Dagaa fishery of Lake Tanganyika. The traditional hand scoop-net yields about 7.5 tons per annum per boat, a modern lift-net will yield about 5 tons of fish per month, while a purse seine will capture 5 to 6 tons per night.

The author discusses general principles with regard to physical and chemical properties of the tropical freshwater habitats and biological factors such as food supply, oxygen lack, and spawning migrations, before he takes up the tropical inland fisheries by habitat. In covering the tropical fisheries of so wide an area (three continents and the East Indies) the author often jumps abruptly from place to place, with the result that his treatment becomes episodic. The habitats as well as fishing gear and methods are effectively illustrated by photographs. Many of the genera of fishes mentioned in the text are illustrated in 3 pages of line drawings of fishes. This book is informative and logically arranged but somewhat discursive.

ELBERT H. AHLSTROM

PLANKTON VOLUME LOSS WITH TIME OF PRESERVATION

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The investigation of plankton volume decrease with ne of preservation is an outgrowth of an investiga- n into the constituent composition of plankton sam- s collected in 1957, a year of marked change in the sonal pattern of plankton volumes surveyed on ises of the California Cooperative Oceanic Fisher- Investigations (Thrailkill 1959, pp. 4-8). The con- tuent study on the 1957 samples was begun about ear after the samples had been collected and the tial volume determinations made. It was soon noted t the earlier plankton measurements could not be plicated. Most samples not only contained a lesser ume than that which had been obtained earlier, c percentage decreases were much greater in sam- s in which non-crustacean plankters predominated.

The difficulty in duplicating plankton volume measurements had been noted as early as 1949, but the magnitude of the volume loss was not appreciated until the systematic remeasuring of volume was begun on the 1957 collections.

The non-replicability of volume measurements stimulated us to make a quantitative study of plankton volume change with time of preservation. The investigation was carried out on a group of 12 test samples, (Table 1) selected to provide a variety of constituent compositions. Volumetric measurements were made on the live collections, on the samples immediately after preservation, and at intervals thereafter until the samples showed little or no further decrease in volume with time; i.e. had reached their stable preserved volumes. The time spacing of observation was empirically determined by the rates of change observed (Table 2).

TABLE 1. COLLECTION DATA FOR PLANKTON HAULS USED IN VOLUME LOSS STUDY[1]

Cruise	Station	Position		Date (1959)	Hour P.S.T.		Vol. water strained ($m.^3$)	Depth of haul (m.)	Depth of water at station (fms.)	Temp. at 10 m. Depth °C
		Lat. N.	Long. W.		Start	End				
2	110.33	29°50.5′	115°52.2′	II-14	1248	1257	279	0–84	50	16.3
	110.65	28°46.5′	117°59′	II-13	1911	1926	492	0–141	1800	17.3
	113.30	29°22.5′	115°17.5′	II-14	1732	1737	194	0–50	30	—
	113.40	29°02′	115°58.5′	II-14	2231	2246	475	0–142	960	16.8
	113.50	28°42′	116°37.5′	II-15	0526	0541	487	0–142	1750	17.1
	120.35	28°03′	114°54′	II-17	1253	1301	282	0–58	45	16.9
	123.42	27°17.2′	115°00.3′	II-19	1846	1901	465	0–140	650	18.3
	130.35	26°19′	113°48.5′	II-21	2216	2230	478	0–138	140	18.8
3	133.30	25°55′	113°07.6′	III-22	0920	0934	472	0–141	104	19.0
7	107.50	29°50.5′	117°23.5′	VII-27	0831	0846	513	0–137	1450	19.3
	107.55	29°40.3′	117°43′	VII-27	0546	0601	508	0–133	1600	20.2
	110.90	28°01′	119°36′	VII-26	0216	0231	544	0–130	2050	21.2

uls taken obliquely with a standard CalCOFI plankton net, 1.0-meter in diameter at mouth, approximately 5 meters in length, and constructed of No. 30xxx grit gauze.

is paper is a revised version of a manuscript presented at the ICES Symposium on Zooplankton Production, 1961 as contribution no. 12. Abstract in Rapp. et Proc.-Verb. 153:78.

TABLE 2. MEASUREMENTS OF VOLUMES OF 12 PLANKTON SAMPLES TO DETERMINE CHANGE IN VOLUME WITH TIME (in milliliters)

Cruise	Station	Before pres.	After pres.	Days after preservation							Months				
				1	2	3	7	10	16	20	1	2	4	12	24
2	110.33	—	38	38	37	37	37	37	35	35	35	35	35	35	35
	110.65	57	47	30	30	30	—	24	24	24	24	24	24	20	20
	113.30	12	10	10	10	10	10	10	10	10	10	10	10	10	10
	113.40	50	42	40	39	—	—	35	35	35	34	34	34	32	32
	113.50	84	63	38	—	—	—	35	34	33	33	33	33	32	32
	120.35	13	12	12	12	—	11	11	11	11	11	11	11	11	11
	123.42	129	61	41	39	—	29	26	26	26	26	24	24	23	23
	130.35	25	19	15	15	—	13	13	13	13	13	13	13	12	12
3	133.30	48	34	25	25	25	25	25	25	25	25	25	25	24	24
7	107.50	93	60	37	—	30	23	21	20	18	17	15	14	13	*12
	107.55	42	26	16	16	16	15	14	13	13	13	13	12	10	*10
	110.90	77	48	38	35	33	31	31	31	31	30	30	29	28	*27

months after collection.

After the samples had attained comparative stability with respect to volume loss, they were intensively analyzed in order to relate volume loss to the constituent compositions of the test samples. The percentage composition by volume of the major groups of plankton organisms in each test sample was determined; the kinds (species) of organisms were identified and enumerated; the proportion of the displacement volume of each sample that was due to included interstitial liquid was determined; the amount of dry substances, organic substances, ash and nitrogen was determined per gram of plankton without interstitial liquid.

FIGURE 1. Stations at which samples were taken for plankton volume loss studies.

The test samples were collected off central Baja California (Fig. 1), eight by the junior author in February, 1959, one in March, 1959, and the remaining three in July, 1959. Water temperatures in 1959 were warmer than usual; plankton volumes were the smallest in a decade. Some groups of organisms that had been conspicuous constituents of the plankton in previous years were absent from the 1959 samples. Among these, the most interesting group was the pyrosomes. These tunicates had become the dominant organism in many hauls made off central Baja California during the mid-1950's particularly from August, 1955 through April, 1957. Previous to their emergence as a dominant plankton constituent, pyrosomes had been so rare as to be curiosities; by 1959 they again had become uncommon and none was taken in the samples reported upon in this paper. Ctenophores also were absent from the test samples. The three test samples taken in July, 1959, were selected in order to have an adequate representation of samples containing salps and doliolids in the volume loss studies; these groups also were markedly less abundant in 1958 and 1959 than during previous years.

The method of measuring displacement volume of "wet" plankton was kept uniform throughout the experiment. The total volume, plankton with its preserving liquid was measured, the plankton was then separated from its preserving liquid, and the volume of the latter determined. The plankton volume, hence was the difference between the two measurements. The consistency of the measurements is one gauge of their reliability. Problems associated with "wet" volume determinations are discussed in a later section.

The percentage composition by volume of the major constituents of the twelve test samples is given in

TABLE 3. PERCENTAGE COMPOSITION BY VOLUME OF MAJOR PLANKTON CONSTITUENTS

Constituents	Cruise 5902								Cruise 5903	Cruise 5907		
	110.33	110.65	113.30	113.40	113.50	120.35	123.42	130.35	133.30	107.50	107.55	110.90
Crustaceans												
Copepods	81	19	68	25	8	77	8	38	20	6	11	19
Euphausiids	*	19	*	11	11	1	18	12	1	2	3	30
Decapod larvae	9	*	4	2	*	11	9	30	25	1	1	17
Ostracods	—	*	*	*	*	—	*	*	*	*	1	*
Amphipods	—	*	—	*	*	—	*	—	—	1	*	*
Other Invertebrates												
Chaetognaths	10	9	25	42	5	10	8	8	45	10	10	16
Siphonophores	*	47	*	8	70	1	*	5	*	21	26	12
Medusae	—	*	—	—	—	—	1	—	—	4	5	—
Salps and Doliolids	*	*	*	*	*	—	48	—	—	52	40	3
Larvaceae	*	*	*	*	*	*	*	1	1	1	1	*
Molluscs	*	6	*	9	6		8	1	8	1	*	1
Fish Eggs	*	—	3	*	*	*	*	5	*	*	*	*
Fish Larvae	*	*	*	3	*	*	*	*	*	1	2	2

* Present, volume less than 0.5%; —no individuals of category observed.

GURE 2. Diagrammatic representation of constituent compositions of test samples expressed as percentage of volume one year after collection.

table 3 and Figure 2. Crustacean constituents are grouped under five categories: copepods, euphausiids, ostracods, amphipods and decapod larvae. The important non-crustacean invertebrate constituents are placed in six categories: chaetognaths, siphonophores, medusae, salps and doliolids, larvaceae, and pelagic molluscs. The only vertebrate categories included are the planktonic stages of fish development—fish eggs and larvae. The volumetric determination of the major constituents was made a year or more after collection, at a time when the preserved volumes had attained comparative stability. This is an important point to keep in mind. Had the determination been made within the first few days of collection, the percentage composition would have been quite different—higher for salps and siphonophores, lower for crustacea, molluscs, and chaetognaths. Had the determination been made before preservation, it would have been more markedly different yet.

Volume shrinkage at preservation.

A striking change in the volume of plankton samples occurs at preservation (Fig. 3). The initial determination of wet volume was made on freshly collected material. Immediately following this measurement, the sample was preserved with three percent buffered formaldehyde solution. A measurement of the preserved volume was made within 10 to 15 minutes of preservation.

Information on volume loss at preservation is available for 11 of the 12 samples. Immediate shrinkage in volume at preservation ranged from seven percent to 53 percent of the live volumes. In only one sample was the percentage loss at preservation as little as ten percent, in only one was it as much as 50 percent; of the other nine samples, three had losses of 11 to 20 percent of the live volume, three had decreases of 21 to 30 percent, and three of 31 to 40 percent.

Volume loss during the first day after preservation.

The rapid shrinkage of the volume of many samples continued during the first 24 hours after preservation. Five samples showed a loss of between 32 percent to 40 percent of the initial preserved volume at the end of one day of preservation; in these, siphonophores and/or salps-doliolids predominated. Three samples showed no volume loss during this period: All three samples were composed almost entirely of crustacaens and chaetognaths. The remaining four samples showed intermediate losses of from five percent to 26 percent; in these samples crustaceans and chaetognaths predominated, but siphonophores and salps made up a part of the volume, except in the sample from station 5903—133.30. The rapid shrinkage of plankton organisms during the first day following preservation probably results from a water loss, especially marked in jelly-like constituents.

Several measurements were made on most samples during the first 24 hours of preservation, but the pattern of observation was not uniform enough from sample to sample to permit their incorporation into table 2. The sample from station 5907-107.50 had the most marked volume decrease of any in the series. After 78 hours of preservation, the volume of the sample was less than a third of the live volume. The decrease noted at intervals during this period was as follows:

Sample from 5907-107.50

Time of observation	*Vol. (ml.)*
Before preservation	93
After preservation ---------- 10 min.	60
" " ---------- 1 hour	56
" " ---------- 4 hours	50
" " ---------- 11 hours	41
" " ---------- 24 hours	37
" " ---------- 78 hours	30

This sample has shown a volume loss on each subsequent measurement. The final measurement (1 ml.), made 22 months after collection, was only 1 percent of the original live volume. Even after one year of preservation, salps and doliolids made up over 50 percent of the volume of this sample. Originally they may have constituted as much as 95 percent of the total volume (discussed in concluding section of paper).

The volume loss in the sample from station 5903 133.30 is different than that for any other sample in that there was a considerable shrinkage at and immediately following preservation but the sample soon reached an equilibrium volume:

Sample from 5903-133.30

Time of observation	*Vol. (ml)*
Before preservation	48
After preservation ---------- 12 min.	34
" " ---------- 3 hours	25
" " ---------- 7 hours	25
" " ---------- 24 hours	25
" " ---------- 2 years	24

The equilibrium volume was reached within three hours of preservation. The change in volume of the sample during the succeeding two years amounted to only 1 ml. or four percent. With regard to the constituent composition of the sample—46 percent by volume consisted of crustacean plankton, 45 percent of chaetognaths and 8 percent pelagic molluscs. Since the exoskeleton of crustacea and the shells of pteropod molluscs prevent marked shrinkage (except for withdrawal of molluscs within their shells), the major adjustment in volume at this station must have occurred in the chaetognaths.

Volume loss subsequent to the first day of preservation.

The volume at one day after preservation is taken as the standard by which to gauge the subsequent shrinkage in plankton volumes of preserved samples. The rapid rate of shrinkage, observed for most samples at preservation and during the first 24 hours thereafter, was markedly slowed down after a day of preservation. Some samples showed little or no volume loss after the first day, others showed a continuing but decelerating decrease with time.

The percentage loss in plankton volumes from the reference volume at one day after preservation is shown for four time intervals in table 4: 10 days,

FIGURE 3. Temporal decrease in volumes of test samples, expressed as percentage of their live volumes.

days, one year, two years. The samples are arranged in this table according to increasing volume loss. In order to relate loss in volume to constituents, the gross composition of each sample is indicated under four categories: crustaceans, chaetognaths, coelenterate-thaliaceans and other constituents.

Four samples showed little or no volume decrease (zero to eight percent) over a two-year period. These samples contained less than one percent by volume of coelenterate-thaliacean constituents and 90 percent to nearly 100 percent of crustacean and chaetognath plankters.

At the other extreme, four samples showed losses of between one-third and two-thirds of their reference volumes. In these samples coelenterate-thaliacean constituents made up 47 percent to 78 percent of the volumes (after one year of preservation).

The samples that were intermediate in volume loss, had a preponderance of crustacean-chaetognath constituents, except for the sample from station 5902-113.50. This latter sample, in which siphonophores made up 70 percent of the volume, had only a moderate volume loss. It is commented upon more fully in a later section.

Constituents

The discussion thus far has dealt with the pattern of temporal decrease in plankton volumes as related grossly to dominant constituents. The specific composition of the samples is treated in table 5. It has been necessary to deal with numbers of individuals rather than their volumes in this table. The table has been assembled with the help of a number of scientists (see Acknowledgements). Specific identifications are not available for several minor constituent groups including ostracods, larvaceae, and some decapod larvae. Ctenophores were absent from the samples, annelids nearly so.

Copepods

Copepods were the dominant constituent in th of the four samples that showed the least volume l with time (Table 3). The three "copepod" samp were collected near the coast, at stations havi depths of 50 fathoms or less (Table 1).

Calanus helogolandicus was the most abundant s cies in two of the three samples (Table 5). In the sa ple from station 5902-110.33 it outnumbered the co bined total of all other copepods by nearly five to o while at station 5902-120.35 it was nearly as numero as all other copepods. At station 5902-113.30, *Calan helgolandicus* was outnumered by *Paracalanus parv* but was still the dominant species in volume. It interesting to note that although these three samp contained a larger number of copepods than the otl test samples, they contained fewer species per samp Copepods made up 6 percent to 38 percent of t volumes in the other test samples.

Euphausiids

This group contributed significantly to the volun of six samples taken at night (11 to 30 percent) b was a minor element in day hauls (one to three p cent). Undoubtedly this resulted from the verti movement of larger individuals into the stratum sa pled at night. Although there is no reason to assu that euphausiids would decrease appreciably in v ume, if at all, during preservation, they were as ciated with samples that showed moderate to hea volume losses. *Euphausia eximia* and *Nyctiphanes si plex* were the most consistently abundant speci *Nematoscelis difficilis, Euphausia gibboides, Sty cheiron affine,* and *Euphausia recurva* were import constituents in one or more of the samples.

TABLE 4. COMPARISON OF PLANKTON VOLUME LOSS WITH CONSTITUENT COMPOSITION OF SAMPLES

Cruise and Station	Percentage Loss in Plankton Volume from Volume at 1 Day After Preservation — Time Interval				Constituent Composition Expressed as Percentage of Volume at 1 Year After Collection			
	10 Days	30 Days	1 Year	2 Years	Crust.	Chaet.	Coel.-Thal.	Other Con
5902—113.30	0	0	0	0	74	26	*	*
5903—133.30	0	0	4	4	46	45	1	8
5902—110.33	3	8	8	8	90	10	*	*
5902—120.35	8	8	8	8	89	10	1	*
5902—113.50	8	13	16	16	19	5	70	6
5902—130.35	13	13	20	20	80	8	6	6
5902—113.40	12	15	20	20	38	42	8	12
5907—110.90	18	21	26	**29	66	16	15	3
5902—110.65	20	20	33	33	38	9	47	6
5907—107.55	12	19	38	**38	16	10	72	2
5902—123.42	37	37	44	44	35	8	49	8
5907—107.50	43	54	65	**68	10	10	78	2

* Present, volume less than 0.5%.
** 22 months.
Abbreviations in Table 4: Crust., Crustaceans; Chaet., Chaetognaths; Coel., Coelenterates; Thal., Thaliaceans; Other Const., Other Constituents.

TABLE 5. SPECIES COMPOSITIONS OF PLANKTON SAMPLES USED IN VOLUME—LOSS STUDY

Crustacean Constituents	Cruise 5902								Cruise 5903	Cruise 5907		
	110.33	110.65	113.30	113.40	113.50	120.35	123.42	130.35	133.30	107.50	107.55	110.90
ds												
ia negligens				100		250						100
nsa			1200			1250						
us gracilis					100							100
lgolandicus	33800	400	3800	3200		14500	300			100	100	600
inor		300	200	900	100	250	600	100	250			200
nuicornis	250	200		200	300			200	250	100		
alanus styliremis	250						200					
acia aethiopica										100	100	200
pinnata										200	200	100
rta	1000			100		250		100	250			
nplex										100		
p.		100		100							200	200
uncata				100								
ropages elongatus												100
p.											100	
olaceus											100	100
socalanus furcatus		400	600	300		1750		500	250	300	100	300
p.	2250	1500	1600	2200	900	2500	1200	2800	4500	900	200	200
caeus spp.	500	300	200		100	1000	100	100		200	100	300
ocalanus vanus		200	1400				300			200	100	100
tideus australis		100		100					250	100	100	
lanus californicus									250			100
assus				100					250			
ileatus				200			200					
naeta acuta				200	100			500				100
ngicornis		100						400	500			
arina												100
edia												100
p.		200		200	100		200	200	500	100		
irella pulchra												100
ius pungens				200								
ptilus acutifrons											100	
ngicornis				200					250			100
piniceps										200		
rorhabdus papilliger				500	100		100	100		100		100
pinifrons								100				
rostylites sp.								100				
docera acutifrons								100				
ispinosa			200									
cutia flavicornis		100							500			
valis		100										
nocera clausi		300		100		250	200			100		
ridia pacifica				100								
aea spp.					100		600	200		500	400	400
ona spp.		200	200	100	200	3250	500	300	250	200	100	100
acalanus denudatus		400	200	500		250	200	2800	250			
arvus	2000		8200		300	4750	200	200	2000			
romamma abdominalis		400		700	300			700			200	800
orealis		900		1500	1900		100	100				1300
racilis		400			100		200	400	1250			100
pp.		100		100	200		100	100				
iphias												200
ncalanus nasutus	250											
phocalanus echinatus								300				
ecithricella abyssalis							100				100	
entata												100
ubdentata		300		300								
ecithrix danae				100								
ttocalanus persecans				100								
nora discaudata				500		500						
leuchaeta sp.				100								200
d. Calanids	1000	700	2200	800	200	250	500	200	250	100		200
ilia mirabilis		65	4	32	8						100	88
phirina sp.											276	16
ausiids												
bhausia eximia A.		8		0	8		40	0			20	96
" " J.		416		40	16		24	4				
" " L.		168		376	0		24	20		100	92	
ibboides A.		8			8		24					
" J.		40					8	3			16	216
" L.		40					0			228	92	8
hemigibba A.		80			1							
" J.		40										
" L.											16	
recurva A.		32			40							16
" J.		360			144							304
" L.					8						12	264
matobrachion flexipes A.		1			1							0
" " J.								4				8
" " L.				8				12				8
matoscelis difficilis A.		8		0	24		0	1				
" " J.				40	16		24	11	16			80
" " L.		40		112	16		0	4				24
gracilis L.		24										

TABLE 5. SPECIES COMPOSITIONS OF PLANKTON SAMPLES USED IN VOLUME—LOSS STUDY—Continued

Crustacean Constituents		Cruise 5902								Cruise 5903	Cruise 5907		
		110.33	110.65	113.30	113.40	113.50	120.35	123.42	130.35	133.30	107.50	107.55	110
Euphausiids—Continued													
N. tenella	A.					1							
" "	J.		1										
" "	L.										4	12	
Nyctiphanes simplex	A.				16	2	4	32	73				
" "	J.		24		24	8	32		288	58	88		
" "	L.		56		216	32	8	64	216	49	40		
Stylocheiron affine	A.		40		56	8		40	2				
" "	J.		96		88	88		8	12	8	12	4	
" "	L.		40		48	48		0	4				
S. maximum	L.				8								
Thysanoessa gregaria	A.		1		8	1							
" "	J.								4				
Thysanopoda aequalis	L.											8	
Ostracods													
Conchoecia sp.		0	296	12	504	108	0	40	68	96	84	36	
Other					24						28	164	
Amphipods													
Eupronoe minuta					3	4							
Eusiropsis riisei			4										
Hyperia schizogeneios											8		
" sp.											4		
Hyperoche mediterranea			4										
Paraphronima crassipes												4	
Phrosina semilunata					10								
Platyscelus serratulus			2										
Primno macropa					3	4							
Pronoe capito								8					
Streetsia challengeri											4		
Viblia armata			3					32					
Viblia stebbingi			3										
Decapod larvae													
Panilurus interruptus												1	
Pleuroncodes planipes		10400	24	3720	2320	24	3200	2728	640	4300	4		
Brachyuran								8	2	16			
Caridean						8					20	36	
Pasiphaeid									12*				
Sergestid											84	28	
Stomatopod							4	8	15				
Other									1				
Other Invertebrates													
Chaetognaths													
Sagitta bierii		50	175	1	440	204		168	112	656	36	19	
S. bipunctata								16			18	4	
S. enflata		500	251	232	780	131	241	456	111	872	21	154	
S. euneritica		2100		633	50	1	210		2		2		
S. hexaptera					1	1					10	4	
S. minima		450	50	1	350	14	154	32	5	192	23	15	
S. pacifica			5			8			3	4	6	40	
S. pseudoserratodentata			18		250	31		160	9	6	197	189	
Krohnitta subtilis			6		78	6			5	192	1	3	
Pterosagitta draco			4			2			3		2		
Siphonophores													
Abylopsis eschscholtzii											4		
Agalma okeni	Nect.		97										
" "	Br.		182										
Bassia bassensis	Sup. N.										4	4	
Chelophyes appendiculata	Sup. N.		17		10	1					118	108	
" "	Inf. N.				8						52	29	
Diphyes bojani	Eud.										4		
Eudoxoides spiralis	Nect.		78		96	4					79	407	
" "	Eud.		280		200				3		114	709	
E. mitra	Eud.							16					
Lensia campanella	Sup. N.											8	
L. challengeri	Sup. N.				17	1		16	11	2	2		
" "	Inf. N.							8	1				
" "	Eud.								9				
L. subtiloides	Sup. N.		9		8						10	6	
" "	Inf. N.		1									1	
Muggiaea atlantica	Nect.	8			9		80		2	8	8		
" "	Eud.			8			8			16			
Nectodroma reticulata	Br.					73							
" "	Gon.					50							
" "	Polyg.					2							
Halistemma rubra	Br.							1					
Sulculeolaria sp.	Inf. N.				1						1	6	
Medusae													
Aglantha digitalis								72			24	120	
Liriope tetraphylla											504	84	
Rhopalonema velatum			8					8				8	

* Juveniles.

TABLE 5. SPECIES COMPOSITIONS OF PLANKTON SAMPLES USED IN VOLUME—LOSS STUDY—Continued

Crustacean Constituents		Cruise 5902								Cruise 5903	Cruise 5907		
		110.33	110.65	113.30	113.40	113.50	120.35	123.42	130.35	133.30	107.50	107.55	110.90
ps and Doliolids (Thaliacea)													
Doliolid oozooid		3	20		33	26					216	97	274
Doliolum denticulatum	Gonzo.										14		10
" "	Phozo.										6		16
" "	S.N.G.	3	4	2								16	
Doliolum gegenbouri	S.N.G.										10	1	
Pegea confoederata	Agg.							272					
Ritteriella picteti	Agg.							24					
Thalia democratica	Agg.										424	574	70
" "	Sol.										72	72	8
olluscs													
Cavolinia inflexa			2		6	5					2	4	
Creseis virgula			1		28		4			15	5		4
Cuvierina columella										1			1
Limacina inflata		8	5010	52	11860	4420	48	4000	352	2410	232	12	630
L. trochiformis			4		2		8	45	23	640			1
Peraclis sp.											1		
Desmopterus sp.											1		
Atlanta leusueri													6
A. peroni			11							55	35		12
A. sp.		8			42		8	3				12	
Pterygiotenthis sp.											1		
Pyrogopsis sp.											2		
rtebrates													
sh Eggs													
Sardinops caerulea		7		12			10						
Engraulis mordax		40	1	469	2		1			3			
Etrumeus acuminatus									40				
Leuroglossus stilbius		1			3								
Bathylagus wesethi											20	8	23
Argentina sialus					3			2					
Nansenia sp.						2					1		
Vinciguerria lucetia		39				2		5			122	16	162
Stomias atriventer					2	1		12			4	2	
Synodus lucioceps							1		1				
Cololabis saira											2		
Citharichthys spp.		79		8			74		8	1			
Paralichthys californicus				13					23				
Pleuronichthys verticalis		1		2			1		1				
Merluccius productus		117		9	15			11	115	4			
Trachurus symmetricus											2		
Chiasmodon sp.												1	
Lepidopus xantusi								6	152	4			
Other		3		11	3	5	1	6	7	13	5	21	3
ish Larvae													
Sardinops caerulea		1		3	1				1				
Engraulis mordax		45		48	414		14	25	4	4			
Bathylagus wesethi											3		6
Nansenia sp.										1			
Vinciguerria lucetia			14		9	10		1	10	2	43	101	170
Cyclothone sp.					2	1		1				2	6
Argyropelecus sp.					2								
Stomias atriventer					1					1			
Macroparalepis macrurus												2	
Ceratoscopelus townsendi													7
Diogenichthys atlanticus					1								
D. laternatus			3		7	2			3		1		5
Electrona crockeri					4								2
Gonichthys tenuiculum								1				1	4
Hygophum atratum					1								1
Lampanyctus mexicanus			3		3			2			8	9	155
L. ritteri			1		9	1					1		
Myctophum californiense											2		
M. margaritatum												2	
Melamphaes spp.			2									3	3
Citharichthys spp.		2		1	5		2	1					
Paralichthys californicus		1											
Pleuronichthys verticalis				1									
Merluccius productus		9		1	4				7	37			
Trachurus symmetricus											1		
Cynoscion sp.				1									
Chiasmodon sp.			1		1								
Lepidopus xantusi					1								
Sebastodes spp.		10		9	26				1				
Other						1							1

Abbreviations in Table 5:

A—Adults
J—Juveniles
L—Larvae
Nect.—Nectophore
Sup. N.—Superior Nectophore
Inf. N—Inferior Nectophore
Br.—Bract
Eud.—Eudoxid
Gon.—Gonophore
Polyg.—Polygastric stage
Gonzo.—Gonozooid
Phozo.—Phorozooid
S.N.G.—Stage not given
Agg.—Aggregate
Sol.—Solitary

Decapod larvae

Decapod larvae were important constituents in the samples studied; they made up 9 percent to 30 percent of the volumes in half of the samples and were present in all. The four samples that showed the least change in volume with time contained 4 percent, 25 percent, 9 percent and 11 percent by volume of decapod larvae, with *Pleuroncodes planipes* contributing all or most of the volume in each instance. The sample in which decapod larvae made the largest percentage contribution to the volume (5902-130.35) contained young of pasiphaeid shrimp. In only this instance did a decapod other than *Pleuroncodes* contribute significantly to test sample volumes.

Chaetognaths

Chaetognaths were consistently important constituents in the test samples; in a third of the samples their volumetric contribution ranged between 16 percent and 45 percent, in another third it was ten percent, and in the remaining third the contribution was between five percent and nine percent.

Chaetognaths were important constituents in the four samples that showed the least volume loss subsequent to the first day of preservation. The sample from station 5902-113.30, containing 26 percent by volume of chaetognaths, showed no loss during this time period and the sample from station 5903-133.30, containing 45 percent by volume of chaetognaths, suffered only a four percent reduction in volume. Thus chaetognaths appear to conserve their "preserved" volume.

We have, however, previously commented upon the fact that there must be a rather marked volume loss in chaetognaths at preservation. At least this is our interpretation of the volume loss in the sample from station 5903-133.30 at preservation. The "preserved" volume is just slightly more than half the "live" volume of the sample.

Chaetognaths made up 45 percent of the preserved volume. The only important constituent groups in this sample other than chaetognaths were crustacea and molluscs, both of which have an external skeleton that precludes shrinkage. The most abundant species of chaetognath in this sample, *Sagitta enflata,* is also the largest and the flabbiest. Most of the initial volume loss in this sample may be attributed to this species.

Siphonophores

The physonectid siphonophores fragment on collection, and the counts of nectophores and bracts, consequently, represent only parts of colonies. The less complex calycophorid siphonophores invariably had the inferior nectophores (if developed) separated from the superior nectophore in the polygastric stage and usually had bracts separated from gonophores in the eudoxid stage. The two types of nectophores are separately tabulated but counts (with one or two exceptions) of the eudoxid stage are based on counts of gonophores.

Siphonophores were an important constituent in over half of the test samples and the dominant constitutent in two. These latter samples offer an interesting contrast. The dominant species in the sample from station 5902-110.65 was *Agalma okeni.* The nectophores of this species have now collapsed, the bracts have become limp. The sample had lost a third of its reference volume after 2 years of preservation. The sample from station 5902-113.50, containing a higher percentage of siphonophores, had lost only a sixth of its reference volume. The important species in this sample was *Nectodroma reticulata,* present in both the polygastric and eudoxid stages. Two polygastric specimens made up half the volume of this sample. These two specimens were removed and separately measured after the tenth day. They showed no subsequent volume loss. The bracts and gonophores of the eudoxid stage of this species occurred in much larger numbers but occupied considerably less volume.

Of the remaining species of siphonophores in the test samples, some hold up less well in preservation than others. Nectophores of *Muggiaea atlantica* collapsed. On the other hand, *Eudoxoides spiralis* held its shape well. *Chelophyes appendiculata,* also stood up well, even with repeated handling. There can be little doubt that much of the volume loss in siphonophores results from collapse of nectophores, bracts and gonophores, and that the amount of volume loss is variable from species to species.

Thaliacea

Salps and doliolids did not contribute significantly to the volumes of the test samples collected in February (5902), except at station 5902-123.42. For this reason, several additional samples containing salps and doliolids were selected and included in the test series during the July cruise.

The three samples which showed the largest volume loss during preservation contained from 40 percent to 52 percent by volume of salps and doliolids after one year of preservation. In two of these, 5907-107.50 and 5907-107.55, the dominant constituent was the salp, *Thalia democratica,* in the other sample from 5902-123.42, the dominant constituent was the salp, *Pegea confoederata.*

Mollusca

The pelagic molluscs in the test samples were almost all shelled forms that retained their "live" volume except for withdrawal into their shells. Only one species *Limacina inflata* was common to abundant in most samples, accounting for most of the volume shown for mollusca. *Limacina trochiformis* was common in only one sample, although it occurred in half of the test samples. *Atlanta* spp. occurred in most samples but did not contribute significantly to the volumes.

Fish eggs and larvae

Fish larvae shrink on preservation, but soon come to an equilibrium volume. Fish eggs shrink but slightly, if at all. Neither would contribute significantly to volume loss after the first day of preserv

on. Fish larvae made up one percent to four percent the volumes in four samples. Most of the contribution was made by *Engraulis mordax* larvae in sample 902-113.40 while in the other three samples the important constituent was *Vinciguerria lucetia* larvae. Fish eggs made up three percent of the volume in station 5902-113.30 and five percent of the volume in station 5902-130.35. In the former, eggs of *Engraulis mordax* predominated, in the latter, those of *Lepidotus xantusi.*

"Wet" displacement volumes of plankton

Throughout the present study, "wet" plankton volumes were determined in a similar manner. The total volume of plankton plus preserving liquid was measured in a graduated cylinder. The sample was then poured into a funnel-shaped silk strainer, the plankton being retained, the preserving liquid being caught in another graduated cylinder. Each sample was allowed to drain for five minutes before a measurement was taken of the preserving liquid. The determination of the "wet" plankton volume was an indirect measurement, based on the difference in the volume of the sample plus its preserving liquid and that of the liquid alone. This type of measurement was utilized in order to keep the handling of the plankton itself to a minimum. In order to minimize loss of liquid by absorption into the screening material the strainer was dampened before use.

The plankton strainer is a cone of No. 56xxx grit gauze attached to a plastic rim. Early experiments had shown that for consistency in volumetric determination, it is essential that the silk strainer be free from contact with other objects. Such contact points often result in "water pockets" which prevent adequate draining.

There is a possibility that the periodic remeasurement of the volumes of the test samples hastens the volume loss in some samples. Volume loss currently is being followed in two collections of salps obtained off southern California in May, 1962. The salps from each collection were separated from the other constituents of the samples before preservation, and divided into two subsamples, one of which has been remeasured five times in four months, the other 24 times. The samples that have been repeatedly measured, show only one to two percent greater volume loss than the samples that have been measured only a few times.

Organism	Percentage decrease in volume during first four months after preservation of sample when remeasured *24 times*	*5 times*
Salpa fusiformis—solitary form	51.5	49.7
Salpa fusiformis—aggregate form	51.2	50.0

Interstitial liquid

A measurement of a drained wet plankton volume consists of two quantities: the plankton itself and the adhering or interstitial liquid. Unfortunately, the latter quantity is far from negligible and is somewhat variable in relative amount from sample to sample.

Investigators have tried to minimize the amount of interstitial liquid by various techniques including blotting, air drying, and vacuum filtration. This problem has engaged the attention of a number of scientists: Ealey 1954, Yentsch and Hebard 1957, Frolander 1957, and Tranter 1960 are recent contributors. Most methods are devised for small samples and are impractical for the large volumes usually obtained on CalCOFI cruises.

We employed a colorimetric technique for determining the amount of interstitial liquid remaining in drained test samples. This technique is based on changes in optical density of an India ink standard that results from dilution by interstitial liquid when a wet plankton sample is added to it (Sutcliffe 1957). The "standard" solution is made up of one part of India ink in 6,000 parts of three percent formaldehyde solution. This is accomplished in two steps: first a stock solution is made up, consisting of one part by volume of India ink and 99 parts of three percent formaldehyde solution; a standard solution is made by mixing one part of the stock solution with 59 parts of a three percent formaldehyde solution. The standard solution is calibrated, using a Klett photoelectric colorimeter. Changes in optical density values that result from progressive dilution of the standard with three percent formaldehyde solution are determined, and a curve prepared.

The drained plankton sample is added to a known volume of standard, the plankton and standard are thoroughly mixed, and a quantity of the liquid is pipetted off. To prevent taking up plankton organisms in the supernatant liquid, the pipette is fitted with a small silk filtering cone. The optical density of the pipetted liquid is then obtained, and the amount of dilution by interstitial liquid is determined from the dilution curve of the standard.

Estimates of the amount of interstitial liquid in the twelve test samples are given in table 6 and Figure 4.

TABLE 6. DETERMINATION BY COLORIMETRIC METHODS OF THE AMOUNT OF INTERSTITIAL LIQUID IN DRAINED "WET" PLANKTON SAMPLES

Cruise & Station	Total volume of drained "wet" plankton (ml.)	Volume of interstitial liquid (ml.)	Volume of organisms only (ml.)	Percentage interstitial liquid
5902				
110.33	35	12.0	23.0	34
110.65	20	5.5	14.5	28
113.30	10	4.0	6.0	40
113.40	32	11.0	21.0	34
113.50	32	5.5	26.5	17*
120.35	11	5.0	6.0	45
123.42	23	7.5	15.5	33
130.35	12	5.0	7.0	42
5903				
133.30	24	8.0	16.0	33
5907				
107.50	12	4.5	7.5	38
107.55	10	4.0	6.0	40
110.90	27	9.0	18.0	33

* Samples from 5902-113.50 not strictly comparable with others (see text)

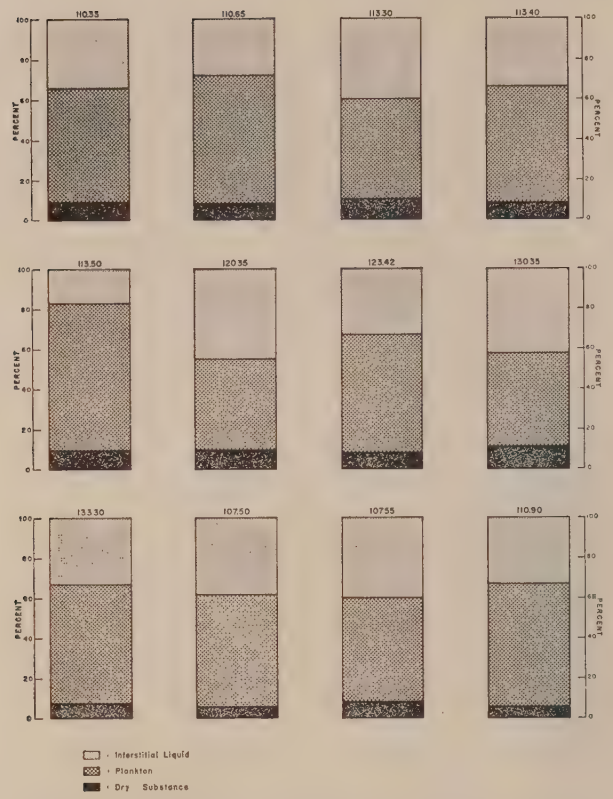

FIGURE 4. Diagrammatic representation of the percentage that interstitial liquid, plankton, and dry substances constituted of the stable preserved volume (weight) measurements of test samples.

The range in values is from 17 percent to 45 percent of the total wet volumes. Except for the sample from station 5902-113.50, no sample had less than one part of interstitial liquid to three parts of plankton and eight of the twelve samples contained between 31-40 percent of interstitial liquid. Several tests were made in order to eliminate adsorption as a possible source of error in our colorimetric determinations. Adsorption was found to be negligible.

The sample from station 5902-113.50 is not strictly comparable to the others, because of the circumstance that half its volume resulted from two specimens of the siphonophore, *Nectodroma reticulata.* Interstitial liquid was separately determined for these as follows:

	Wet vol. (ml.)	Amount of interstitial liquid in ml.	Vol. of plankton alone (ml.)	Percentage of interstitial liquid
Portion containing two specimens of Nectodroma	16.0	0.2	15.8	1
Remainder of sample	16.0	5.3	10.7	33

The portion of the samples containing the two specimens of *Nectodroma* caused practically no change in the optical density of the standard. This observation is interesting for two reasons: it shows how little interstitial liquid may adhere to larger specimens of "jellies", and it affords indirect evidence that adsorption of the colloidal carbon particles of the standard on the surface of the specimens was negligible. The remainder of the sample contained about 33 percent interstitial liquid, hence approximates the median value for interstitial liquid in the other test samples.

Our values of 28 to 45 percent interstitial liquid in the 12 test samples are only slightly higher than those reported by Riley, Stommel and Bumpus (1949) and Frolander (1957). The former investigators removed interstitial liquid by rolling plankton animals on filter paper. They obtained weight losses of between 20 and 30 percent in most samples tested in a group of about 20, but had losses as high as 45 percent. Frolander reported average volume losses of 19.4 percent for one group of 10 samples, 27.5 percent for a second group of 10 samples when interstitial liquid was removed by vacuum filtration.

Removal of interstitial liquid by blotting

The commonest techniques for removing interstitial liquid is by blotting. Determinations of interstitial liquid were made by both blotting and colorimetric measurement on a sample of 2,000 individuals of *Calanus helgolandicus,* separated from 5902-110.33. Dry weight and ash weight determinations also were made on this sample.

Determinations made on 2,000 *Calanus helgolandicus*

Wet volume	2.8 ml.
Interstitial liquid	1.5 ml.
Copepods only	1.3 ml.
Wet weight	2.68 g.
Blotted weight	1.15 g.
Dry weight	0.1694 g.
Ash weight	0.0077 g.
Percent ash/dry weight	4.55%

Interstitial liquid was determined by the colorimetric technique and found to be approximately 5 percent of the wet volume. The sample was washed with formaldehyde solution, allowed to drain for five minutes, and its wet weight determined. Interstitial liquid was then removed by blotting and air drying. The sample was again weighed and the weight loss attributable to interstitial liquid was determined to be approximately 60 percent of the wet weight. Considering the limits of precision of the two techniques the resulting values for interstitial liquid are closely comparable. However, the values for interstitial liquid are greater than those obtained in mixed plankton samples.

In our experience the blotting technique is most reliable when used on organisms with an exoskeleton. Blotting of samples containing salps or siphonophores can give an overestimate of the interstitial liquid b

TABLE 7. DRY WEIGHT DETERMINATIONS OF PORTIONS OF TEST SAMPLES

Station	Wet[1] weight	Percentage of wet weight due to plankton	Estimated weight of plankton alone	Dry weight (grams)	Ash weight (grams)	Dry substance per gram of plankton (grams)
110.33	3.420	66	2.257	0.215	0.0130	0.095
110.65	4.250	72	3.060	0.260	0.0223	0.085
113.30	1.285	60	0.771	0.085	0.0061	0.110
113.40	6.240	66	4.118	0.340	0.0350	0.083
113.50	2.565	67	1.719	0.170[2]	0.0133	0.099
120.35	1.985	55	1.092	0.110	0.0097	0.101
123.42	2.475	68	1.683	0.140	0.0090	0.083
130.35	2.520	58	1.467	0.170	0.0164	0.116
133.30	1.810	67	1.211	0.095	0.0114	0.078
107.50	1.825	63	1.150	0.065	0.0116	0.056
107.55	1.115	60	0.669	0.055	0.0048	0.082
110.90	2.820	67	1.876	0.180	0.0188	0.096

[1] Wet weight of plankton plus interstitial water.
[2] Two polygastric specimens of **Nectodroma reticulata** excluded from determinations.

removing part of the body liquids from the organisms (overdrying). The volume of the two polygastric specimens of *Nectogroma reticulata* from station 5902-113.50 was reduced to from 17 to 14 ml. by overdrying with a blotter. When put back in preservative these specimens regained their former volume after several days. Overdrying of salps such as *Iasis zonaria* on the other hand, has resulted in a permanent decrease in preserved volume. Overblotting of some kinds of salps and ctenophores has resulted in the physical breakup of specimens. Physical rupture of specimens was more often observed when the technique of vacuum filtration was employed to remove interstitial liquid, however. Vacuum filtration also may induce overdrying of specimens. This technique has to be used with caution.

For most plankton samples, weight and volume are readily convertible: 1 ml. of plankton weighs approximately one gram. This comparison has been made on a number of plankton samples and constituents; of the common constituents only pteropods do not conform. Hence in some parts of the discussion that follows, we have used grams or milliliters of plankton interchangeably. In many of our experiments, determinations of both weight and volume were made.

Dry weight

A dry weight determination of plankton has certain definite advantages. Water is eliminated, both interstitial and that within the organisms, only organic and inorganic substances contained in the bodies of the plankters remain. This determination, therefore, is a more basic one for evaluating the potential food value of the standing crop of plankton than a determination based on wet volume or wet weight.

Dry weight determinations made on fractions of the 12 test samples are given in table 7. These determinations were made 23 to 26 months after collection of the test samples (in June, 1961). The plankton used for dry weight determinations had two categories of organisms removed, pteropods and fish eggs and larvae. The former category was excluded because it was felt that their calcareous shells would make the dry weight determinations hard to interpret. Riley and Gorgy (1948) have shown that the dry weight of pteropods was approximately 83 percent ash and only 17 percent organic matter.

The 12 test samples are arranged in table 8 in descending order with respect to amount of dry substances (D.S.) per gram of plankton. Also contained in this table are organic substances (O.S.) and nitrogen content (ΣN) expressed in mg. per gram of

TABLE 8. COMPARISONS OF DRY SUBSTANCES, ORGANIC SUBSTANCES, ASH, AND NITROGEN CONTENT OF TEST SAMPLES, WITH THEIR CONSTITUENT COMPOSITIONS

Cruise & Station	Per gram of plankton			Per 100 mg. D.S.			Constituent composition (% by vol.)			
	D.S. mg.	O.S. mg.	ΣN mg.	O.S. mg.	Ash mg.	ΣN mg.	Crustacea	Chaetognaths	Coelenterates	Thaliacea
5902–130.35	116	105	13.3	90.4	9.6	11.4	85	9	5	1
5902–113.30	110	102	11.7	92.8	7.2	10.6	74	26	*	*
5902–120.35	101	92	9.7	91.2	8.8	9.6	89	10	1	*
5902–113.50	99	91	13.6	92.2	7.8	13.7	44	11	45	*
5907–110.90	96	86	10.6	89.6	10.4	11.0	68	17	12	3
5902–110.33	95	89	10.8	94.0	6.0	11.4	90	10	*	*
5902–110.65	85	78	9.3	91.4	8.6	10.9	40	10	50	*
5902–113.40	83	74	8.8	89.7	10.3	10.7	43	48	9	*
5902–123.42	83	78	9.5	93.6	6.4	11.4	38	9	1	52
5907–107.55	82	75	10.2	91.3	8.7	12.3	16	10	32	42
5903–133.30	78	69	8.3	88.0	12.0	10.7	50	49	*	1
5907–107.50	56	46	5.3	82.2	17.8	9.5	10	10	25	55

* Present, but less than 0.5% by volume.
D.S., Dry Substances; O.S., Organic Substances; ΣN, Nitrogen Content.

plankton, and in mg. per 100 mg. of dry substances (symbols adopted from Krey, (1958)). For ready comparison of the relation between D.S., O.S., and ΣN values, and constituent composition, the approximate percentage by volume of the four major groups of plankton organisms are listed for each sample.

A further summary of the material contained in table 8 follows:

Dominant organism	No. samples	Per 1 g. plankton		Per 100 mg. D.S.			Per 100 mg. O.S.
		D.S. ave. mg.	D.S. range mg.	O.S. ave. mg.	Ash ave. mg.	ΣN ave. mg.	ΣN ave. mg.
Crustacea	5	103.6	(95–116)	91.6	8.4	10.8	11.8
Crustacea-chaetognath	2	80.5	(78–83)	88.8	11.2	10.7	12.0
Crustacea-coelenterate	2	92.0	(85–99)	91.8	8.2	12.3	13.4
Thaliacean	3	73.7	(56–83)	89.0	11.0	11.1	12.5

The range in dry solids (D.S.) values is from 56 mg. to 116 mg. per gram of preserved plankton. The five samples in which crustaceans predominate (66 to 89 percent of sample volumes) averaged 103.6 mg. D.S. per gram plankton as compared to 73.7 mg. D.S. per gram plankton for samples in which salps and doliolids (thaliaceans) were dominant (i.e., made up 42 to 55 percent of sample volumes). The two samples containing crustacea and chaetognaths in about equal volumes averaged only 80.5 mg. D.S. per gram plankton, while the two samples in which crustacea and coelenterates each made up 40 to 50 percent of the volumes, averaged 92.0 mg. D.S. per gram plankton. The values for D.S. are strikingly more alike than had been anticipated. More of this later.

A number of authors give D.S. and O.S. determinations of plankton samples or of constituents. We have chosen for comment the following: Lovegrove (1961), Riley and Gorgy (1948), Tranter (1960), and Krey (1958).

Tranter (1960, table 6) reports D.S. values for plankton ranging from 24 mg. (salp swarm) to 160 mg. (sample predominantly euphausiids), with most values falling within the range given by us. His determinations on salp samples were made soon after collection, before the salps had "concentrated" to the extent that they had in our test samples.

Riley and Gorgy (1948) reported on D.S., O.S., and ash for representative plankton groups. The values they obtained for four constituent groups were as follows:

Constituent	Quantity in mg. per gram of constituent			Percent ash weight of dry weight
	D.S.	O.S.	Ash	
Copepods	173	147	26	15
Chaetognaths	134	98	36	27
Euphausiids	107	93	14	13
Thaliaceans	17	6	11	65

Their values are instructive in several respects. For one thing they point up the marked differences that obtain in both dry substances and organic substances between constituent groups at time of capture. The thaliaceans contain only four percent as much O.S. per gram of organism as do copepods, and six percent as much O.S. per gram of organism as do chaetognaths. Their values also show a higher inorganic (ash) content than was present in our test samples at equilibrium volume.

As noted previously, dry weight determinations were made on 2000 specimens of *Calanus helgolandicus*. The D.S. value of this sample is 147 mg. per gram of *Calanus;* ash content was only 6.7 mg., hence organic matter constituted 140 mg. per gram of *Calanus*. The latter value is quite similar to that given by Riley and Gorgy for copepods; the ash content is markedly less. The amount of biomass of *Calanus helgolandicus* required to yield one gram of organic matter is 7.15 grams. Lovegrove (1961) quotes a value of 6.8 grams of biomass per gram of organic matter for the closely related species, *Calanus finmarchicus*.

There appears to be both a water loss and an inorganic salt loss from the bodies of plankton organisms during preservation. The ash content of our samples ranged from 6.0 to 17.8 percent of the D.S. with only four values exceeding 10 percent. This is markedly less than the ash weights reported for the principal constituent groups by Riley and Gorgy. The three samples of our material in which salps dominated had ash contents that amounted to 6.4, 8.7, and 17.8 percent of the D.S. determinations. Based on Riley and Gorgy's determinations, the ash weight of these samples should have approximated 50 percent of the dry weight, had the inorganic salts been fully retained by the organisms during the period of volume concentration.

Krey (1958, table III) gives information on ΣN as well as O.S. and D.S. for various kinds of plankton samples. The ΣN values for four samples in which copepods predominated (80 to 100 percent copepods) ranged between 7.5 and 11.1 mg. per 100 mg. O.S. Our nitrogen values for "plankton" samples in which copepods dominated are somewhat higher, averaging 11.8 mg. N per 100 mg. O.S. Our higher values could result from a loss of some of the oils from the bodies of copepods, which would be shown as an increase in the protein content of O.S. Even so, our test samples with mixed constituents had a somewhat higher protein content (ΣN) than the samples in which crustacea were the dominant component.

Discussion

This study has drawn attention to the fact that the volume of organisms in a preserved sample is always less than their live volume. All of the test samples showed volume decreases subsequent to preservation.

The percentage decreases in volumes that were observed at selected time intervals are summarized in table 9. The time period required by the samples to reach their equilibrium volumes follows.

Equilibrium volume attained	No. samples
Immediately following preservation	1
1 day	0
10 days	1
1 month	1
1 year	7
2 years	2

Ten of the 12 test samples attained equilibrium volume within a year of collection. The remaining two samples showed only trivial losses during the second year. For all practical purposes, preserved plankton volumes can be considered to become stabilized within a year after collection.

The decreases in volume of plankton that occurred in test samples are from 15 to 87 percent of the live volumes. The amount of decrease is related to constituent composition, being least for samples in which crustacea made up most of the volume, greatest for samples in which salps were dominant.

The constituent compositions of samples when determined subsequent to preservation are not a measure of the amounts (by volume or weight) of the living constituents. Constituent determination of living material, however, is usually impractical. This cannot be done at sea on programs such as CalCOFI in which we are engaged. Hence this determination must be made at some subsequent time. The time to be preferred is when the samples have reached a relatively stable volume. Crustacean samples reach an equilibrium volume quite soon after preservation—salp samples slowly. Even salp samples show little change after one year of preservation, hence constituent volume determinations made one year after collection should be reproducible.

The constituent compositions (expressed as percentage by volume) of samples that have reached stable preserved volumes are useful, as long as their limitations are kept in mind. They would differ markedly from the original constituent compositions (percentage by volume) in some samples and would approximate them in others. In order to derive even moderately reliable estimates of the original constituent compositions of preserved samples, more information is needed concerning volume losses suffered by the various constituent groups and by the more abundant species within these groups. Several volume loss studies on individual constituents are underway at our laboratory.

Rough estimates of the original constituent compositions were derived for several of the test samples containing a mixture of crustacean-chaetognath and jelly-like constituents. In these computations a shrinkage of 50 percent was allowed for custacea, chaetognaths and molluscs. This is an "outside" estimate, for the crustacean-chaetognath samples showed a 15 to 50 percent decrease from their live volumes.

Sample from 5902-123.42

(Volume before preservation: 129 ml.; volume at time of constituent determination: 23 ml.)

	Crustaceans-Chaetognaths	*Thaliaceans-Coelenterates*
Percent by volume-one year after collection	51	49 (48% Salps)
Volume	11.7 ml.	11.3. ml.
Estimated original volume	23 ml.	106 ml.
Estimated percent by volume original collection	18	82

Sample from 5907-107.50

(Volume before preservation: 93 ml.; volume at time of constituent determination: 13 ml.)

	Crustaceans-Chaetognaths	*Thaliaceans-Coelenterates*
Percent by volume-one year after collection	23	77
Volume	3.0 ml.	10.0 ml.
Estimated original volume	6.0 ml.	87 ml.
Estimated percent by volume in original collection	6	94

The number of organisms in a sample does not change with time. Counts made several years after collection should not differ from counts made at the time of collection. Very few zooplankton constituents disappear from a preserved sample. Even ctenophores, such as *Pleurobrachia*, which break up in time and seemingly dissolve in the supernatant liquid, still leave

TABLE 9. PERCENTAGE DECREASE IN VOLUME OF PRESERVED PLANKTON SAMPLES FROM ORIGINAL LIVE VOLUME, GIVEN FOR SELECTED TIME INTERVALS

Cruise & Station	Orig. vol. ml.	Final vol. ml.	Percentage decrease from original live plankton volume					
			Imm. after pres.	1 day after pres.	10 days after pres.	1 mon. after pres.	1 year after pres.	2 years after pres.
5902-120.35	13	11	92.3	92.3	84.6	84.6	84.6	84.6
5902-113.30	12	10	83.3	83.3	83.3	83.3	83.3	83.3
5902-110.30	(44)	35	(87)	(87)	(85)	(80)	(80)	(80)
5902-113.40	50	32	84.0	80.0	70.0	68.0	64.0	64.0
5903-133.30	48	24	70.8	52.1	52.1	52.1	50.0	50.0
5902-130.35	25	12	76.0	60.0	52.0	52.0	48.0	48.0
5902-113.50	84	32	75.0	45.2	41.6	39.3	38.1	38.1
5902-110.65	57	20	82.4	52.6	42.1	42.1	35.1	35.1
5907-110.90	77	27**	62.4	49.4	40.3	39.0	36.4	35.1
5907-107.55	42	10	61.9	38.1	33.3	30.1	23.8	23.8
5902-123.42	119	23**	47.3	31.8	20.2	20.2	17.8	17.8
5907-107.50	93	12**	64.4	39.7	22.6	18.3	14.0	12.9

** 22 months after collection.
Values in parentheses are estimates.

TABLE 10. ESTIMATES OF NUMBERS OF COPEPODS, EUPHAUSIIDS, AND CHAETOGNATHS PER MILLILITER OF SAMPLE IN 12 TEST SAMPLES

Station	Sample vol. ml.	Copepods			Euphausiids			Chaetognaths		
		Est. vol. ml.	Est. number	No. per ml.	Est. vol. ml.	Est. number	No. per ml.	Est. vol. ml.	Est. number	No. per ml.
110.33	35	28.35	41,300	1455	*	80	—	3.50	3100	885
110.65	20	3.80	7,765	2040	3.80	1443	380	1.80	509	285
113.30	10	6.80	20,004	2940	*	240	—	2.50	867	347
113.40	32	8.00	13,932	1655	3.50	840	240	13.45	1949	145
113.50	32	2.55	5,108	2005	3.50	470	135	1.60	398	250
120.35	11	8.45	31,000	3665	0.11	68	620	1.10	605	550
123.42	23	1.85	5,900	3190	4.15	728	175	1.85	832	450
130.35	12	4.55	10,600	2330	1.45	261	180	0.95	250	265
133.30	24	4.80	12,000	2500	0.25	152	610	10.80	1922	180
107.50	12	0.72	3,600	5000	0.25	244	975	1.20	316	265
107.55	10	1.10	2,676	2430	0.30	272	905	1.00	418	430
110.90	27	5.10	6,804	1335	8.10	1080	133	4.30	2450	570

* Present, volume less than 0.5%.

behind tentacle sheaths and comb rows as evidence of their presence. Hence, counts of organisms in a sample constitute a more conservative value than volume or weight.

Nevertheless, counts of individuals, to have value in quantitative assessments of biomass of standing crop, must be related in a meaningful way to volume or weight. Unless this is done, counts are of dubious utility. Obviously, 1,000 *Paracalanus parvus* are not equivalent in any meaningful way, except in number, to 1,000 *Calanus helgolandicus*. The volume occupied by the *Calanus* would be many times that occupied by the *Paracalanus*. Still other complications arise when dealing with numbers of organisms. Each species has a series of developmental stages that differ markedly in size. It might take a hundred or more larvae of *Euphasia eximia*, for example, to equal the mass of one adult.

Estimates of the number of individuals per ml. of wet volume have been derived for three groups: copepods, euphausiids, and chaetognaths (Table 10). Similar estimates can be derived for the other important constituent groups in the test samples. Copepods range in number from 1,335 to 5,000 individuals per ml., euphausiids from 133 to 975 individuals per ml., and chaetognaths from 145 to 885 individuals per ml. There are over seven times as many euphausiids per ml. in the sample from 5907-107.50 as in the sample from 5902-113.50, over six times as many chaetognaths in the sample from 5902-110.33 as in the sample from 5902-113.40. Obviously, data on numbers of individuals of a constituent group have limited value until they are related to volume or weight.

Although wet plankton volumes are over-estimates of the volume occupied by the organisms, due to included interstitial liquid, the amount of the latter can be determined with some precision. From determinations on test samples, interstitial liquid ordinarily makes up from 28 to 45 percent of the volumes of wet plankton samples, hence the amount is variable from sample to sample. Even so, a fairly adequate "average" value for interstitial liquid in our test samples would be 35 percent of the wet plankton volume.

The dry weight of a plankton sample is less subject to change with time than the "wet" weight (or volume). The major change in weight (volume) of "wet" plankton is due to water loss, which has the effect of concentrating the organic constituents. However, water loss is accompanied by an inorganic salt loss, which lowers the ash content of preserved samples. Organic substances appear to be more fully retained in the bodies of preserved plankton organisms. We have found only traces of nitrogen in the preserving liquids of undisturbed plankton samples that have been stored for considerable periods of time. Oils, however, are less fully retained. A verification of this loss is readily made on *Calanus*-rich samples in which the extracted oil can be seen as free-floating droplets.

Lovegrove (1961) has discussed some of the problems that arise in drying plankton for D.S. and O.S. determinations. Higher D.S. values are obtained when samples are dried by desiccation than when water is removed by oven drying, especially if the drying is done at temperatures above 60° C.

Most workers have related dry weights to wet weights of organisms. There has been little consistency in use of fresh or preserved material, perhaps because it was not appreciated that the volume measurements of live and preserved materials are not comparable. As is evident from our studies, volume determinations of preserved material will be less than "live" volumes by a variable amount depending on constituent composition and the time interval intervening since preservation. Obviously, dry weights should be related to the weight of freshly collected material, from which interstitial water has been removed. There is considerable merit in the oft-made suggestion that a plankton sample should be partitioned on collection, one part to be preserved, the other to be used for a dry weight determination. Technical difficulty in carrying out this suggestion has prevented its adoption as a standard technique.

A dry weight determination can be expressed as the amount of organic substances in a standard volume of water (1000 m^3, for example). This determination bypasses most of the technical problems associated with relating dry weight to wet weight of plankton.

We have been intrigued by the strikingly similar dry weight determinations obtained on our test samples after two years of preservation, despite the marked differences in constituent compositions. The range in values of 56 mg. to 116 mg. per gram of preserved plankton (without interstitial liquid) constitutes a range of only 2X; furthermore, most values were grouped much more closely together. Apparently the nutrient compositions of samples have been made roughly comparable per unit volume (or weight) of plankton through the process of concentration of the volumes of jelly-like constituents relative to that of crustaceans and other constituents with an exoskeleton. An implication of this finding is that plankton volume determinations, *per se,* made on plankton samples that have reached their equilibrium volumes after a year of preservation, constitute meaningful measures of the standing crop of zooplankton.

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LITERATURE CITED

Ealey, E. H. M. 1954. Letter to the Editor: A new method of net plankton determination. *J. Cons. int. Explor. Mer.,* 19(3), p. 368.

Frolander, F. 1957. A plankton volume indicator. *J. Cons. int. Explor. Mer.* 22(3), p. 278-283.

Krey, J. 1958. Chemical determinations of net plankton, with special reference to equivalent albumin content. *J. Mar. Res.* 17, p. 312-324.

Lovegrove, T. 1961. The effect of various factors on dry weight values. *ICES Symposium* on *"Zooplankton Production," Contribution No.* 27, 14 p., published in part in *Rapp. et Proc.-Verb.* 153: p. 86-91, Sept. 1962.

Riley, G. A. and S. Gorgy. 1948. Quantitative studies of summer plankton populations of the western North Atlantic. *J. Mar. Res.* 7 p. 100-121.

Riley, G. A., H. Stommel, and D. F. Bumpus. 1949. Quantitative ecology of the plankton of the western North Atlantic. *Bull. Bingham oceanogr. Coll.* 12(3), p. 1-169.

Sutcliffe, W. H., Jr. 1957. An improved method for the determination of preserved plankton volumes. *J. Limnol. Oceanogr.* 2(3), p. 295-296.

Tranter, D. J. 1960. A method for determining zooplankton volumes. *J. Cons. int. Explor. Mer.* 25(3), p. 272-278.

Thrailkill, J. R. 1959. Zooplankton volumes off the Pacific coast, 1957. *U.S. Fish and Wildlife Service, Spec. Sci. Rep.: Fish.* 326, 57 p.

Yentsch, C. S. and J. F. Hebard. 1957. A gauge for determining plankton volumes by the mercury immersion method. *J. Cons. int. Explor. Mer.* 22(2), p. 184-190.

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USE OF A DISCRIMINANT FUNCTION IN THE MORPHOLOGICAL SEPARATION OF ASIAN AND NORTH AMERICAN RACES OF PINK SALMON, *ONCORHYNCHUS GORBUSCHA* (WALBAUM)

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ABSTRACT

Pink salmon (*Oncorhynchus gorbuscha*) collected from representative North American and Asian areas in 1957 were studied to determine how effectively morphological characters would separate continental stocks. A discriminant function was computed from three morphological characters and the Karaginskii and Kodiak-Cook Inlet samples as continental morphotypes. Applying this function, North American pink salmon populations from Kodiak Island and eastward were well separated from the Asian morphotype. Indications were that very few if any pink salmon from these areas were present in the high-seas samples examined. Predominance of pink salmon of Karaginskii morphotype were found in samples taken as far east as 175° West longitude.

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INTRODUCTION

Among the investigations carried out by the United States Fish and Wildlife Service under the research program of the International North Pacific Fisheries Commission is the determination of the continental origin of pink salmon (*O. gorbuscha*) found in the North Pacific Ocean and Bering Sea.

One method of attacking this classification problem is to analyze a selected set of morphological characters. This implies selection of characters that separate races with a low risk of misclassification, and combination of these into a method with a known risk. Tagging and catch data are used as corroborating evidence of continental separation based on morphological characters.

The purposes of this study are: (1) to select morphological characters for Asian and North American pink salmon; (2) to define continental morphotypes based on these characters; and (3) to estimate the contribution of each morphotype to samples of possibly mixed origin. The results of this study should help the United States Section of the International North Pacific Fisheries Commission to carry out its duties in connection with fishery conservation problems in the North Pacific Ocean.

ACKNOWLEDGMENTS

The authors wish to acknowledge Dr. W. F. Royce, Fisheries Research Institute of the University of Washington, for critical review of the manuscript and the following Bureau of Commercial Fisheries personnel: R. A. Fredin for suggested use of the discriminant function; D. D. Worlund for statistical guidance and many helpful suggestions as well as programming the analysis for the IBM 650 computer; and D. D. Worlund and E. DeCorvet for the electronic computations.

METHODS AND MATERIALS

Methods of Sampling

Samples of pink salmon were collected from the principal fisheries of North America in 1957. An attempt was made to obtain the samples during the most active period of fishing. Mature fish were taken

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from their spawning streams whenever possible, but most were obtained from estuarine fisheries.

No pink salmon were obtained from Siberia; however, salmon of probable Siberian origin were obtained from Japanese mothership fisheries operating off the east coast of the Kamchatka Peninsula and in the Okhotsk Sea. These samples were caught in Japanese commercial gillnets with mesh size of 4–8/10 inches stretched measure.[1] Samples from the Japanese fisheries of Hokkaido Island supplemented Asian collections.

High-seas samples were obtained from gillnet catches of the Japanese high-seas fishery and from Japanese, Canadian and United States research vessels. The research vessels used a standard string of gillnets with mesh sizes of $2\frac{1}{2}$, $3\frac{1}{4}$, $4\frac{1}{2}$ and $5\frac{1}{4}$ inches stretched measure.

All the specimens were two-year-old fish. Samples were preserved by freezing and subsequently transported to the Seattle Biological Laboratory of the Bureau of Commercial Fisheries in Seattle for examination.

Appendix A (p. 86) lists the location, date and number of pink salmon collected in 1957.

Methods of Data Collection

Ten morphological characters were examined for possible use in separating the various populations of pink salmon (Figure 1). They were as follows:

1. *Vertebrae* were counted, beginning with the atlas and terminating with the urostyle. Specimens with abnormal or fused vertebrae were not included in the analysis.

2. *Ventral gill rakers* were counted on the ventral arm of the first left gill arch commencing with the raker in the bend of the arch and including the rudimentary rakers at the anterior terminus. Branched rakers having a common base were counted as one. If the existence of a rudimentary raker was uncertain, the particular gill arch was re-radiographed or stained[2] for positive identification.

3. *Gill rakers* were counted on the first left gill arch using criteria and methods identical to those for character 2.

4. *Branchiostegal rays* on the left side of the head were also counted. Disagreement in the number of rays was resolved by staining and again counting structures.

5. *The number of dorsal fin rays* included all r mentary as well as principal fin rays. Occasion a small bone was found anterior to the first rudim tary ray in the dorsal and anal fins. This was coun if it showed indications of developing into a fin by the presence of a small sharp projection. If bone showed no sign of developing into a fin ray was excluded.

6. *Anal fin rays* were counted using methods a criteria identical to those for character 5.

7. *Pectoral fin rays* were counted on the left fin. difficulties were experienced in counting this charac

8. *Circuli* from the focus of the scale to the annu were counted.

9. *The scale length* from the focus to the annu was measured (magnified 42 times).

10. *The intermediate zone* is the scale length of first ten circuli from the focus (magnified 42 time

Permanent photographic records of characters through 7 were obtained by X-raying, and permane scale impressions were made on acetate cards. T structures on every radiograph were counted by o trained worker and verified by another. Each sc was read by an experienced fishery scientist. Sc samples from selected areas were subjected to repeat readings to verify accuracy. The body length fr the end of the hypural plate to the middle of the e was also measured on each fish. This measureme was not used as a character to classify salmon; ho ever, correlation between length and the other char ters was tested for significance to detect possible b due to selectivity of various mesh sizes. Charact significantly correlated with length were not used.

In the salmon examined, the sample size for sc characters was often smaller than the sample size the seven characters counted on radiographs. T was particularly true in stream samples where t scales were more frequently absorbed due to approac ing sexual maturity.

Methods of Analysis

The discriminant function analysis as developed Fisher (1936) is a multivariate normal technique which individual observations within a sample m be classified to one of two groups (morphotypes) the basis of a selected set of morphological variat This type of analysis was used for pink salmon m phological characters. To apply this analysis it

[1] Distance between opposite knots.

[2] Modified stain method of Hollister (1934).

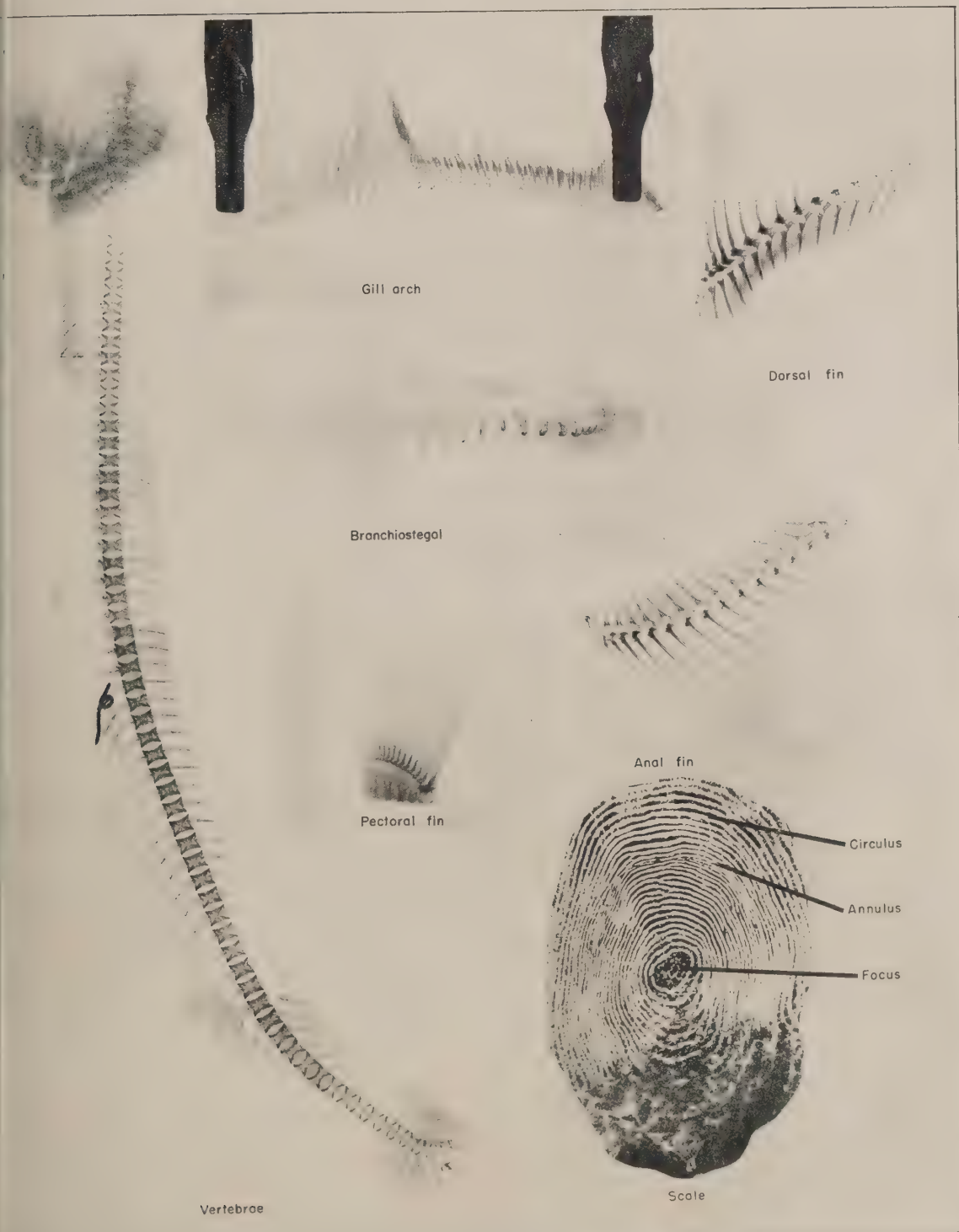


Figure 1. Scale characters and radiographed meristic characters.

necessary to assume that high-seas-caught fish of unknown origin were derived from the races represented by the samples composing the two morphotypes since all individuals will be classified into one or the other regardless of true origin. Additional statistical assumptions require the data to have jointly normal distributions with a common dispersion (variance-covariance) matrix in the populations selected for use as inshore morphotypes and into which specimens are to be classified. There is no single test for a multivariate normal distribution, although satisfaction of certain other conditions can indicate conformity in some of the important aspects. These conditions include common variance, normality of distributions, common correlation and linearity of regression. If common variance and common correlation exist as required for a multivariate normal distribution, the conditions for a common dispersion matrix are simultaneously satisfied.

RESULTS

Examination of Intra-Area Variability

The ten morphological characters were examined for two possible sources of intra-area sampling variability, sexual dimorphism and correlation with fish length. Since mixtures of races could also cause extraneous variability, examination was restricted to stream samples which were assumed to be of one race.

Appendices B-1 (p. 88) and B-2 (p. 90) show that th variances between sexes are significantly different onl for ventral gill rakers. None of the means are signi cantly different between sexes, but the value for tot vertebrae is close to the 95 percent critical valu Heterogeneity of variances generally biases analys of variance tests toward more frequent significant values. Despite this presumed influence on the mea of the ventral gill raker data, there is no evidence sexual dimorphism. The sexes have been combine for further analyses.

Some types of fishing gear are size selective. Co relation of morphological characters with fish leng could introduce bias. Appendices B-3 (p. 91) and B (p. 91) show that only the numbers of circuli and sca length had significant correlation coefficients, and th only 4.62 percent and 8.73 percent of the variation i these characters was attributable to length. None the other morphological characters was significantl correlated to fish length. No serious bias due to co relation of fish length with morphological characters indicated in these data.

Selection of Morphotypes

Karaginskii and Kodiak-Cook Inlet were selecte as continental morphotypes.

Some direct and some circumstantial evidence available on the origin of the populations composi

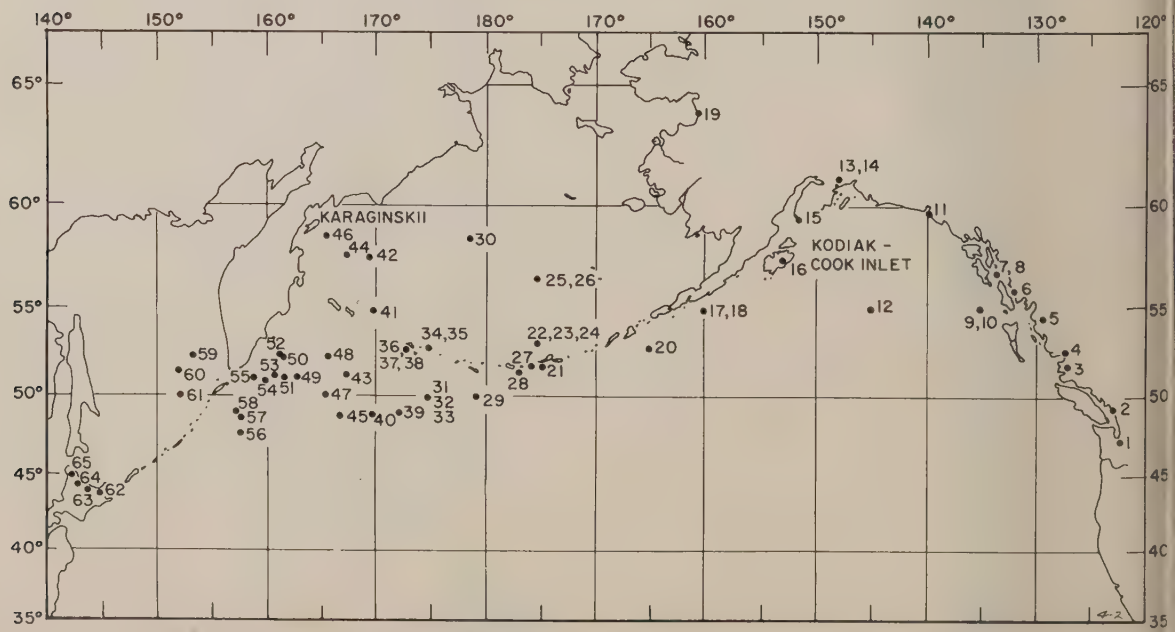
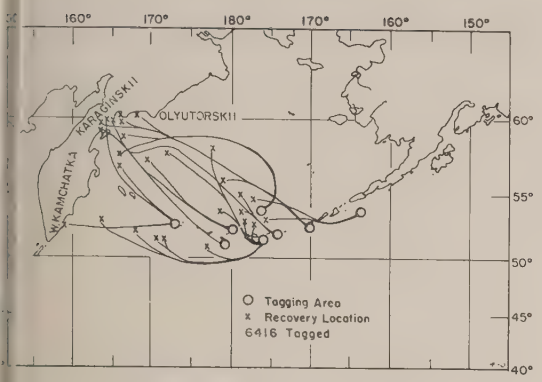


Figure 2. Sampling locations for 1957 pink salmon (see Tables 5 and 6).



E 3. 1957 tag recoveries of pink salmon tagged during 7.

of the high-seas samples collected in 1957 (Figure The United States tagging vessels tagged 6,416 -seas-caught pink salmon during 1957 (Annual ort, International North Pacific Fisheries Commis- 1958). Fish were tagged along the Aleutian ds and to a limited extent offshore both north south of the Aleutians. All recoveries (68) of pink salmon tags were made by the U.S.S.R. he east coast of the Kamchatka Peninsula or by apanese high-seas fishery, westward of the tagging and between the areas of tagging and Kamchatka ure 3). None was recovered in west Kamchatka, apanese Okhotsk Sea fishery, the Hokkaido Island -based fishery or in North American fisheries or m surveys. Most Soviet recoveries were made e Karaginskii region of the Kamchatka Peninsula.

he Karaginskii region is reported to be an area airly heavy pink salmon production, though it not approach the level of production reported for west Kamchatka region (Taguchi, 1957). Al- gh samples representing elements of the latter e included in 1957 pink salmon collections from Japanese Okhotsk Sea fishery, samples from the ediate proximity of the Karaginskii region were obtained. Therefore, it was necessary to consti- a Karaginskii morphotype from the high-seas ries samples taken closest to the Karaginskii on. Three such samples, taken at 58°12′N., 48′E.; 57°02′N., 169°11′E. and 57°26′N., 27′E. were used. Of the 99 pink salmon so ained, 25 were excluded for lack of complete sets norphological data. These samples were statisti- y identical in the morphological characters used in analysis and may be pooled (Appendix C–1, p. 92).

Although there is no direct evidence that populations er than those from Karaginskii occurred in the a of tagging, pink salmon from other Asian and also from North American areas could have been present on the high seas. For example, samples are included that were obtained beyond the areas of tagging. As previously stated, west Kamchatka appears to be the most productive Asian pink salmon area and might be considered as the morphotype into which high-seas pink salmon should be classified. However, as will be demonstrated later, with Karaginskii as one morphotype in the discriminant function, the west Kamchatka populations differ more from most North American pink salmon races than do the pink salmon of Karaginskii. It follows that Karaginskii samples provide the more efficient continental morphotype.

Without direct evidence, selection of samples from North American areas for use as a morphotype must be made wholly on intuitive grounds. Catches of pink salmon in 1957 in the Central Alaska district, to which the Kodiak Island and Cook Inlet areas are major contributors, totaled about 6.5 million fish (U.S. Fish and Wildlife Service, 1959). This figure plus the corresponding escapement indicates an abundance well above that of any other North American area reasonably close to the high-seas sampling area.

Knowledge concerning pink salmon of the Western Alaska district north of the Alaska Peninsula and of the Aleutian Islands is meager. However, these races are thought to be minor, particularly when compared to a Japanese high-seas catch of about 21 million pink salmon during the 1957 season (Fukuhara and Tanonaka, 1958). On these bases, Kodiak Island and Cook Inlet samples were chosen to typify the second morphotype. Samples from these areas have common variances and means and may be pooled to form a Kodiak-Cook Inlet morphological type (Appendix C–1, p. 92).

Selection of Characters

Data were collected for ten meristic characters, seven from pink salmon morphology and three from scale characteristics. Past experience indicated that some of these characters would contribute little if anything to separation of the two morphotypes. To eliminate characters contributing little or nothing to the separation, we computed a discriminant function (Rao, 1952) using all ten characters. Three characters contributed approximately 98 percent of the separation; the remaining seven characters were dropped from consideration in the tests of assumptions and final analysis which follow. This procedure greatly simplified the calculations for the discriminant function.

The selected characters and their approximate percentage contribution to the total separation of the morphotypes as indicated by the preliminary discriminant function were: total vertebae, 62 percent; intermediate scale zone length, 32 percent; and dorsal fin rays, 4 percent. With the morphotype samples determined and the useful characters selected, we can test a greatly reduced volume of data for conformity to the requirements of the discriminant function.

TABLE 1. Results of tests for homogeneity of variance in selected morphological characters of the 1957 pink salmon morphotypes.

Morphological character	Kodiak-Cook Inlet variance	Karaginskii variance	Ratio	Critical 1-percent F value[1]
Total vertebrae	0.7168	0.9583	1.3370	1.55
Dorsal fin rays	0.5460	0.5413	1.0087	1.63
Intermediate scale length	3.5197	3.9948	1.1350	1.55
	$N=167$	$N=74$		

[1] Actual significance level of two percent for this two-tailed test.

TABLE 2. "r" values and the results of common correlation tests on the Karaginskii and Kodiak-Cook Inlet morphotypes between all pairs of characters.

Character pairs	"r" values		"t" values $d.f.=\text{inf.}\ (\infty)$ $t_{.01}=\pm 2.58$
	Kodiak-Cook Inlet	Karaginskii	
Intermediate scale length Total vertebrae	−0.0761	−0.0115	0.4553
Intermediate scale length Dorsal fin rays	−0.0140	0.0144	0.1999
Total vertebrae Dorsal fin rays	0.0676	0.1671	0.7108

Common variance is required between e identical character of the two morphotypes. T feature can be tested by a variance ratio in which larger variance is the numerator and the smal variance the denominator. The values obtained compared with the values in published F-distribut tables with the appropriate degrees of freedom.

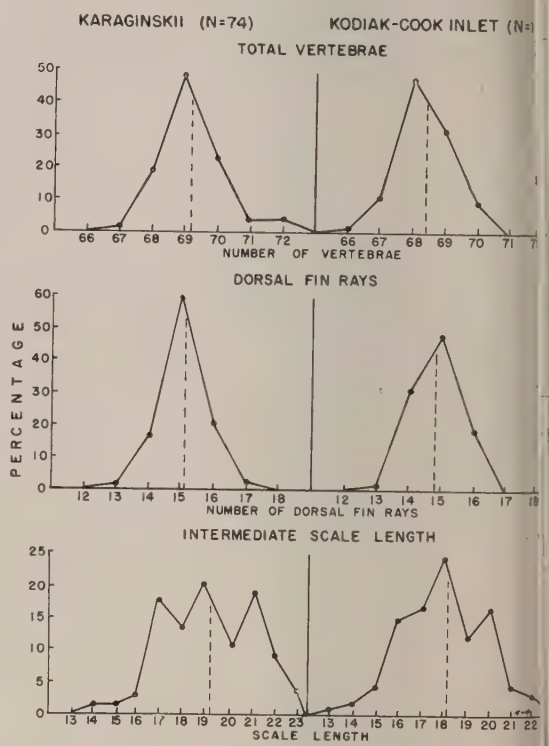


FIGURE 4. Frequency distributions of morphological charac used in separating Karaginskii and Kodiak-Cook Inlet pink salmon morphotypes. Broken lines indicate means.

TABLE 3. Results of tests for linearity of regression in three morphological characters used in racial separation of 1957 samples of pink salmon.

Independent variable	Dependent variable	F value	Degrees of freedom	$F_{.01}$
Karaginskii morphotype				
Intermediate scale zone length	Dorsal fin ray counts	0.2572	8,64	2.79
Dorsal fin ray counts	Intermediate scale zone length	1.0332	3,69	4.08
Dorsal fin ray counts	Total vertebrae counts	1.6648	3,69	4.08
Total vertebrae counts	Dorsal fin ray counts	1.0276	4,68	3.61
Total vertebrae counts	Intermediate scale zone length	0.8579	4,68	3.61
Intermediate scale zone length	Total vertebrae counts	0.1466	8,64	2.79
Kodiak-Cook Inlet morphotype				
Intermediate scale zone length	Dorsal fin ray counts	0.8673	9,156	2.53
Dorsal fin ray counts	Intermediate scale zone length	0.7791	2,163	4.75
Dorsal fin ray counts	Total vertebrae counts	0.7746	2,163	4.75
Total vertebrae counts	Dorsal fin ray counts	1.0815	3,162	3.91
Total vertebrae counts	Intermediate scale zone length	1.1956	3,162	3.91
Intermediate scale zone length	Total vertebrae counts	1.0648	9,156	2.53

TABLE 4. The variance-covariance matrix and calculation of the discriminant function for the 1957 pink salmon[1].

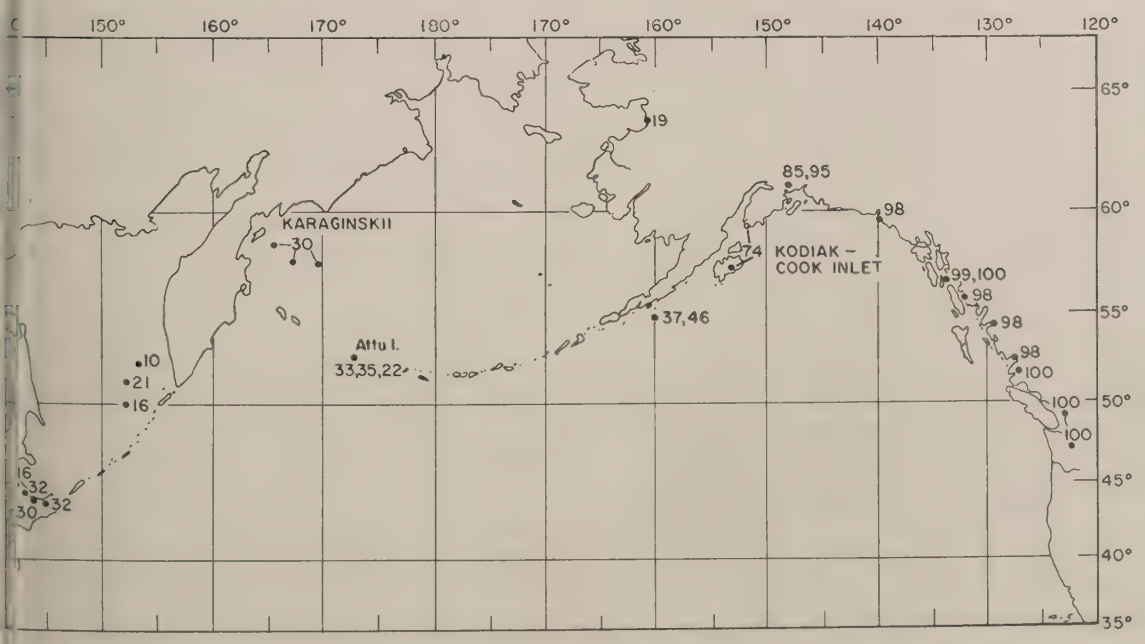
		Variance-covariance matrix			
		X_1	X_2	X_3	Mean Diffs.
d vertebrae	1.	0.790550	0.066141	−0.090931	0.831446
al fin rays	2.		0.544553	−0.007034	0.242758
rmediate scale length	3.			3.664841	1.177375
	4.				0.000000
		Discriminant function matrices			
	11.	1.000000	0.083665	−0.115022	1.051731
	12.	0.083665	0.539019	0.000574	0.173195
	13.	−0.115022	—	3.654382	1.273010
	14.	1.051731	—	—	−0.874458
	22.	0.155217	1.000000	0.001065	0.321315
	23.	−0.115111	0.001065	3.654381	1.272826
	24.	1.024848	0.321315	—	−0.930108
	33.	−0.031499	0.000291	1.000000	0.348301
	34.	1.064941	0.320944	0.348301	−1.373435

$Y = 1.064941\,X_1 + 0.320944\,X_2 + 0.348301\,X_3$

photype Means:	Total vertebrae (X_1)	Dorsal fin rays (X_2)	Intermediate scale zone length (X_3)
Karaginskii	69.202703	15.081081	19.243243
Kodiak-Cook Inlet	68.371257	14.838323	18.065868

Y (Karaginskii) = 85.239419
Y (Kodiak-Cook Inlet) = 83.865985
$Y_0 = 84.552702$

ing Pivotal Condensation Method (Rao, 1952).



RE. 5. Percentage of each stream or inshore 1957 pink salmon sample classified as of Kodiak Island-Cook Inlet morphotype.

The results of this procedure for the selected morphotypes and characters are shown in Table 1. None of the ratios show significant differences between the variances of the two morphotypes for any character at the 2–percent level, with evidence that the larger variances are less than one and one-half times the smaller variances.

For small samples there exists no adequate test for normality (Fisher, 1944; Cochran, 1947). Frequency distribution curves are given in Figure 4 for the three characters of each of the two morphotypes. No radical departures from normality are evident. Fisher has indicated that very drastic departures are required before statistical procedures based on normality are disturbed. On this basis the normality of the data is accepted as adequate for the discriminant function.

To test the assumption of common correlation, we calculated sample correlation coefficients (r's) between all possible pairs of characters in each morphoty The coefficients are given in Table 2. The test common correlation used is that given by Snede (1956), in which the "r" values are converted tables to Fisher's "z" values. The differences tween the "z" values of the two areas for the sa characters are divided by the standard error of difference to obtain "t" values with infinite degr of freedom. Significance is then determined in usual fashion from the published tables of "t". T "t" values obtained are listed in the right column Table 2. The "t" values show no significant ferences between the correlation coefficients of e pair of characters of the morphotypes when compa with the tabled "t" values. The assumption common correlation between the morphotypes these data is accepted.

The final assumption requiring verification is t

TABLE 5. Classification of fish in 1957 pink salmon stream and inshore samples as to percentage resembling each morphotype

Map. No.[1]	Source	Location	Date	Sample size	Percentages: Kodiak-Cook Inlet	Karagins
1	Puget Sound	La Conner, Washington	9/6	76	100.00	0.00
2	Fraser River	Gulf of Georgia fishery	9/4	65	100.00	0.00
3	Rivers Inlet	—	8/13	81	100.00	0.00
4	Skeena River	Tyee	7/30	82	97.56	2.44
5	Nass River	Sommerville Island	8/4	59	98.31	1.69
6	Ketchikan	Point Eaton	8/14	97	97.94	2.06
7	Petersburg	Windham Bay	8/8	90	98.89	1.11
8	Petersburg	Tenakee	7/30	14	100.00	0.00
11	Yakutat	Situk-Ahrnklin River	8/1	85	97.65	2.35
13	Pr. Wm. Sound	Anderson Bay	7/16	34	85.29	14.71
14	Pr. Wm. Sound	Anderson Bay	8/1	42	95.24	4.76
15	Cook Inlet	Tutka Bay	7/4	82 } 169	73.96	26.04
16	Kodiak Island	Uyak Bay	7/30	87 }		
17	King Cove	Shumagin Island	7/11	68	36.76	63.24
18	King Cove	Shumagin Island	7/26	24	45.83	54.17
19	Unalakleet	Unalakleet River	7/9	67	19.40	80.60
36	Attu Island	Gravel Pit	8/4	55	32.73	67.27
37	Attu Island	Gravel Pit	8/5	46	34.78	65.22
38	Attu Island	Lake Cornica	8/–	27	22.22	77.78
42	Nippon Suisan[2]	57°02′ N., 169°11′ E.	7/12	27 }		
44	Nippon Suisan[2]	57°26′ N., 167°27′ E.	7/13	26 } 74	29.73	70.27
46	Nippon Suisan[2]	58°12′ N., 166°48′ E.	7/15	21 }		
59	Okhotsk Sea	52°08′ N., 154°15′ E.	6/24	51	9.80	90.20
60	Okhotsk Sea	51°16′ N., 153°39′ E.	7/14	81	20.99	79.01
61	Okhotsk Sea	50°52′ N., 153°28′ E.	7/4	68	16.18	83.82
62	Hokkaido Island	Shari fishery	9/–	53	32.08	67.92
63	Hokkaido Island	Abashiri fishery	9/–	56	30.36	69.64
64	Hokkaido Island	Tokoro fishery	9/–	62	32.26	67.74
65	Hokkaido Island	Yubetsu River	9/–	62	16.13	83.87

[1] Numbers refer to sampling locations as shown in Figure 2.

[2] Nippon Suisan Fisheries Company (Karaginskii).

linearity of regression. An analysis of variance technique (Dixon and Massey, 1957) was employed which variance about the regression line was tested against the variance within groups. All three possible pairs of characters were tested, with first one of each pair as the independent variable, and then the other. The results given in Table 3 show no indication of departure from linearity by any of the combinations. Details of the testing and the numerical values will be found in Appendix C–2 (p. 94).

Construction of Karaginskii and Kodiak-Cook Discriminant Function

With assumptions having been provisionally verified, a discriminant function of the form $Y = l_1X_1 + l_2X_2 +$ was calculated using the data of the variance-covariance matrix from the top of Table 4. A detailed description of the technique is available from Rao (1952), who also demonstrates that it produces the best linear discriminant function obtainable. The coefficients in row 34, Table 4, are the coefficients (l's) needed for the equation. The equation thus appears as $Y = 1.064941\,X_1 + 0.320944\,X_2 + 1.301\,X_3$, where X_1 is the total vertebae count, X_2 the dorsal fin ray count and X_3 the intermediate length. The last value in row 34 is the variance commonly called D^2.

The probability of correctly classifying an individual into either of the two populations considered as morphotypes, provided the individual is actually from one of the populations, is equal to the probability that a normal deviate with mean zero and standard deviation of one will be less than, or equal to, $D/2$. In the present analysis, D^2 has a value of 1.373435; thus D equals 0.585968. The probability of correctly classifying a single fish into its morphotype is 72.08 percent, again provided the fish originated from one of the two populations.

Classification of Samples into Morphotypes

Let us consider first the effect of classifying, with the calculated discriminant function, fish which we are reasonably sure did not originate from one of the two morphotype populations. Table 5 and Figure 6 show the results of classifying the pink salmon of the 1957 samples collected in streams or inshore near the spawning grounds. Classification is presented as the percentage of specimens in each sample resembling the Kodiak-Cook Inlet morphotype (Y values less than 84.553) and percentage of specimens in each sample resembling the Karaginskii morphotype (Y values greater than 84.553). With 3,455 fish to classify, it is not practicable to present individual Y values in this paper; therefore the mean of the Y values from each sample is given. In general, the samples are arranged in the table by longitude from east to west with sample size also given.

Since the discriminant function produces a linear equation, the mean Y values obtained from whole samples from presumed known races may also be placed on a straight line, as shown in Figure 6. With this type of presentation it becomes apparent that samples from the presumed Asian races have discriminant scores about equal to or higher than that of the Karaginskii morphotype using the morphological

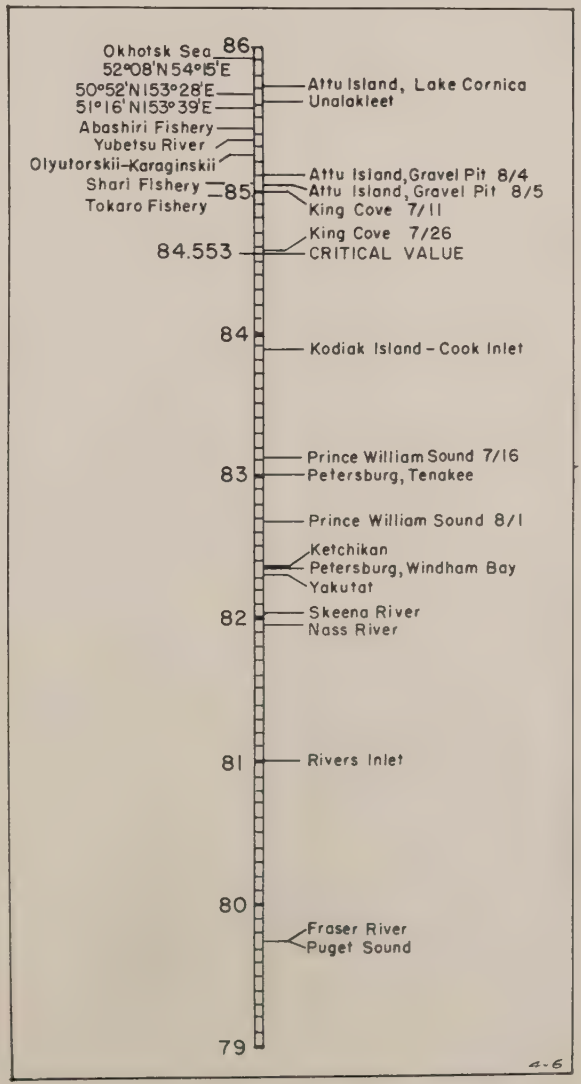


Figure 6. Linear comparison of mean discriminant scores of 1957 pink salmon samples from presumed known races.

TABLE 6. Classification of fish in high-seas 1957 pink salmon samples as to percentage resembling each morphotype.

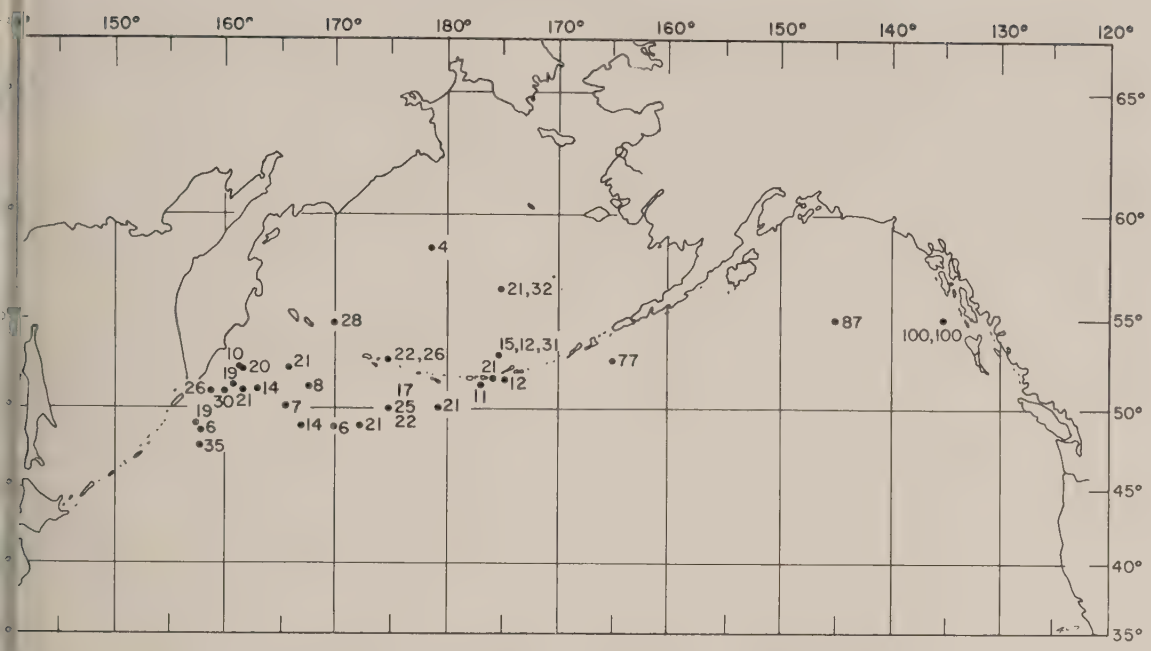
Map. No.[1]	Source	Location	Date	Sample size	Percentages	
					Kodiak-Cook Inlet	Karaginsk
9	MV *Key West*	55°00′ N., 135°00′ W.	7/31	9	100.00	0.00
10	MV *Key West*	55°00′ N., 135°00′ W.	8/1	28	100.00	0.00
12	MV *Key West*	55°00′ N., 145°00′ W.	7/12	54	87.04	12.96
20	MV *Attu*	53°40′ N., 165°00′ W.	7/25	13	76.92	23.08
21	MV *Commander*	12 mi. so. Atka Is.	6/6	33	12.12	87.88
22	MV *Attu*	53°00′ N., 175°00′ W.	6/8	59	15.25	84.75
23	MV *Attu*	53°00′ N., 175°00′ W.	6/9	49	12.24	87.76
24	MV *Attu*	53°00′ N., 175°00′ W.	6/10	42	30.95	69.05
25	MV *Pioneer*	56°00′ N., 175°00′ W.	6/29	99	21.21	78.79
26	MV *Pioneer*	56°00′ N., 175°00′ W.	6/30	57	31.58	68.42
27	MV *Commander*	6 mi. so. Little Tanaga Is.	6/8	28	21.43	78.57
28	MV *Commander*	8 mi. so. Adak Is.	6/20	27	11.11	88.89
29	*Kano Maru*	50°05′ N., 179°56′ E.	6/8	42	21.43	78.57
30	Nippon Suisan[2]	58°10′ N., 177°17′ E.	7/1	23	4.35	95.65
31	MV *Pioneer*	50°00′ N., 175°00′ E.	6/10	124	16.94	83.06
32	MV *Pioneer*	50°00′ N., 175°00′ E.	6/11	83	25.30	74.70
33	MV *Pioneer*	50°00′ N., 175°00′ E.	6/12	96	21.88	78.12
34	MV *Pioneer*	53°00′ N., 175°00′ E.	6/14	95	22.11	77.89
35	MV *Pioneer*	53°00′ N., 175°00′ E.	6/20	189	25.93	74.07
39	*Kano Maru*	49°37′ N., 171°00′ E.	6/1	29	20.69	79.31
40	*Kano Maru*	49°45′ N., 170°24′ E.	5/25	17	5.88	94.12
41	Nippon Suisan[2]	54°51′ N., 170°24′ E.	7/6	18	27.78	72.22
43	Nippon Suisan[2]	51°41′ N., 167°27′ E.	6/28	24	8.33	91.67
45	*Etsuzan Maru*	49°02′ N., 167°25′ E.	5/31	86	13.95	86.05
47	*Etsuzan Maru*	50°03′ N., 166°47′ E.	6/1	83	7.23	92.77
48	Nichiro[3]	52°33′ N., 166°04′ E.	6/20	28	21.43	78.57
49	Nippon Suisan[2]	51°39′ N., 162°16′ E.	7/1	29	13.79	86.21
50	Nichiro[3]	52°28′ N., 161°42′ E.	6/30	51	19.61	80.39
51	Nichiro[3]	51°39′ N., 161°40′ E.	7/20	47	21.28	78.72
52	Nichiro[3]	52°36′ N., 161°21′ E.	7/10	49	10.20	89.80
53	Nippon Suisan[2]	51°28′ N., 161°15′ E.	7/5	31	19.35	80.65
54	Nichiro[3]	51°22′ N., 160°15′ E.	7/22	50	30.00	70.00
55	Nichiro[3]	51°13′ N., 159°45′ E.	7/24	42	26.19	73.81
56	Nippon Suisan[2]	48°57′ N., 158°30′ E.	7/15	68	35.29	64.71
57	Nippon Suisan[2]	49°02′ N., 158°21′ E.	7/14	32	6.25	93.75
58	Nippon Suisan[2]	49°14′ N., 158°11′ E.	7/10	27	18.52	81.48

[1] Numbers refer to sampling locations as shown in Figure 2.
[2] Nippon Suisan Fisheries Company.
[3] Nichiro Fisheries Company.

characters and the equation outlined previously.

A similar situation prevails with the Kodiak-Cook Inlet morphotype. The mean Y value of the morphotype is 83.866 and all other North American areas so far sampled have lower mean Y values with the present discriminant function, with the exception of pinks taken from the Shumagin Islands, from the Unalakleet River and from Attu Island. Pinks from these areas collected in 1957 are indistinguishable from those of Karaginskii with the characters now utilized. Whether this resemblance to Karaginskii morphotype prevails in all pink salmon originating in North Amer and Aleutian Island areas north and west of Alaska Peninsula is not known at present.

Evidently, then, pink salmon of Asian o captured on the high seas are as likely (72 perce the time) to be classified as Karaginskii-type fi are fish from Karaginskii proper. From rec released catch statistics of the U.S.S.R. (Internat North Pacific Fisheries Commission, 1959), it



IGURE 7. Percentage of each high seas 1957 pink salmon sample classified as of Kodiak Island-Cook Inlet morphotype.

that many of the fish in high-seas samples taken
de the tagging area were from the highly produc-
evest Kamchatka spawning areas. These records
late a catch of 53,100 metric tons of pink salmon
the west Kamchatka area and only 22,300 metric
for the entire east Kamchatka coast, including
ginskii. West Kamchatka fish taken on the high
will be classified as Karaginskii-type more often
Karaginskii fish themselves.

Similarly, high-seas-caught pink salmon originating
Kodiak Island streams and North American
nental streams east of Kodiak will be classified
portionately (72 percent or more) as Kodiak-Cook
type fish.

l pink salmon are, of course, not exclusively from
or the other of the two morphotype populations.
discriminant function obtained does classify such
nto the morphotype of their originating continent
a minimum probability of correct classification
percent. Certain North American stocks west
north of the Kodiak-Cook Inlet area which were
phologically similar to Karaginskii fish in 1957
be expected.

esults of classifying pink salmon of unknown
n obtained on the high seas are presented in
e 6 as percentage of fish in each sample classified
the two morphotypes. From the accompanying
(Figure 7) showing percentage of each sample
nbling the Kodiak-Cook Inlet type, there is little statistical evidence of Kodiak-Cook Inlet fish westward of 175° West longitude. Approximately 28 percent of Karaginskii pink salmon are expected to have a discriminant score mis-identifying them as Kodiak-Cook Inlet fish. The high-seas samples west of 175° West longitude range only as high as 35 percent resembling the Kodiak-Cook Inlet morphotype, which is probably no greater than expected in random sampling of pure Asian stocks or of stocks from the previously excepted areas.

Some of the fish in these samples may have originated from Attu Island, the Unalakleet River or the Alaska Peninsula. The discriminant classification of Alaska Peninsula fish is not clearly defined at this time since no mainland samples from the area were available. Two samples obtained from traps just offshore in the Shumagin Islands area indicated relatively high percentages of Karaginskii-type fish. The time of capture (July 11 and 26) and degree of maturity suggest a not-too-distant spawning site. Whether this was on the Bering Sea coast, on an Aleutian island or on the Alaska Peninsula is not known.

High-seas fishing operations took few pink salmon eastward of 175°W. to 160°W. longitude. The U.S. research vessel MV *Attu* fished repeatedly in June and August of 1957 between longitudes 160°W. to 170°W. and latitudes 50°N. to 56°N., obtaining very few pinks. Early in June, this same vessel had caught fair numbers of pinks per set along 175°W. The MV *Pioneer* fished

north and south along 175°W. in late June and early July, obtaining very few pinks after having caught them in fair abundance along 175°E. in mid-June. When the MV *Pioneer* returned to 175°E. in mid-July very few pinks were obtained. Still another vessel, the MV *Paragon*, fished steadily along 175°W. from mid-August without netting a single pink salmon.

The low catches of pink salmon east of 170°W. longitude, and their relative abundance to the west, suggest a scarcity of North American pink salmon in the high-seas sampling areas of the western Bering Sea. On one station (sample 20), at 165°W. and south of the Aleutian Chain at which a few pinks (13) were caught, a relatively higher percent of Kodiak-Cook Inlet type was indicated. Very high percentages of Kodiak-Cook Inlet morphotype fish were found in three additional high-seas samples well to the east in the Gulf of Alaska.

SUMMARY AND CONCLUSIONS

The evidence, while based on limited data, suggests little intra-area variability in pink salmon morphological characters. Factors considered included sexual dimorphism and correlation of morphological characters with fish length. Two characters taken from the scales proved to be slightly correlated with length. These characters, however, were not used in the racial analysis.

Ten morphological characters, three from scale structures and seven from other physical characteristics, were considered for use in a discriminant function racial analysis of 1957 pink salmon collections from the North Pacific Ocean and Bering Sea. Three characters—total vertebrae, intermediate zone and dorsal fin rays—provided approximately 98 percent of the separation in a discriminant function.

These three characters were tested for assumptions necessary to satisfy multivariate analysis; the other seven characters were discarded. The required assumptions were fulfilled.

Tests for conformity of the distributions of the morphological characters employed in the Fisher discriminant function indicated the presence of multivariate normal distributions as required.

The assumption that the individuals of unknown origin (high-seas catches) were derived only from the two sources employed as morphotypes could not be completely satisfied. However, the linear discriminant function classified 72 percent or more of all sampled Asian pink salmon as Karaginskii morphotype and 72 percent or more of all sampled North Amer fish as Kodiak-Cook Inlet morphotype except for in samples from Attu Island, the Unalakleet R and the Shumagin Islands which more frequ resembled the Karaginskii morphotype.

The high-seas fish of unknown origin can thu classified to most probable continent of origin or basis of their resemblance to one or the other o two morphotypes even though they may have c from another region of the same continent. A high-seas-caught pink salmon which came from Island, the Unalakleet River, the Shumagin Isl and perhaps other areas north and west of the Al Peninsula must, for the present, be excepted.

Results of the classificatory analysis of 1957 h seas-caught pink salmon indicated the obvious d nance of Karaginskii morphotype in all samples 175°W. longitude westward. Some of these fish have come from the excepted areas; however runs of Attu Island and the Unalakleet Rive known to be small in comparison to the size o Japanese high-seas catch and presumably could greatly influence the distribution pattern obtained if they could be separated from Asian stocks. samples from the Shumagin Islands traps coul representative of a morphotype to be found in nearby Alaska Peninsula areas, the eastern Ale Islands or in Bristol Bay. If this is the case, and are from larger runs, it is difficult to understan scarcity of pink salmon from 175°W. eastward o high seas.

One small sample of 13 pinks taken south o Aleutian Chain and west of the Shumagins at 16 was classified mainly as being Kodiak-Cook morphotype. It seems most likely that the Shum fish classified to the Karaginskii morphotype from a local North American stock of restricted tribution and that the pink salmon of Karag morphotype obtained from 175°W. westward probably actually Asian fish.

Three additional samples obtained well to the at 135°W. and 145°W. longitude were almost en composed of Kodiak-Cook Inlet morphotype s mens.

Conclusions drawn from the 1957 data will a certainly apply only to odd-year spawning fish, the two-year life history of this species ensures com genetic isolation between adjacent year cl Furthermore, extension of the results to other odd broods would have to be made with caution, for only the single year's data from pink salmon tr

the magnitude of parent-offspring variability as yet be accurately assessed.

LITERATURE CITED

AN, W.G. 1947. Some consequences when the assump- for the analysis of variance are not satisfied. *Biometrics*, 22–38.

WILFRID J., AND FRANK J. MASSEY, JR. 1957. Introduc- to statistical analysis. Second Edition, McGraw-Hill Co., Inc. (New York), 488 pp.

R.A. 1936. The use of multiple measurements in nomic problems. *Annals of Eugenics*, 7(2): 179–188.

R.A. 1944. Statistical methods for research workers. h Edition, Oliver and Boyd, Ltd. (Edinburgh), 350 pp.

ARA, FRANCIS M., AND GEORGE K. TANONAKA. 1958. A nese high-seas salmon fishery in the North Pacific since 9. *U.S. Fish and Wildlife Service, Commercial Fisheries Review*,): 1–16.

STER, GLORIA. 1934. Clearing and dyeing fish for bone y. *Zoologica*, 12(10): 89–101.

INTERNATIONAL NORTH PACIFIC FISHERIES COMMISSION (INPFC). 1958. Annual Report for the year 1957. International North Pacific Fisheries Commission (Vancouver, Canada), 86 pp.

INPFC. 1959. Pacific salmon catch statistics of the Union of Soviet Socialist Republics 1940–1958 (as given to the International North Pacific Fisheries Commission by the All-Union Research Institute of Marine Fisheries and Oceanography, Moscow). International North Pacific Fisheries Commission (Vancouver, Canada), 4 tables (mimeographed).

POWERS, E.A. 1959. Fishery statistics of the United States, 1957. *U.S. Fish and Wildlife Service, Statistical Digest*, No. 44, 429 pp.

RAO, C. RADHAKRISHNA. 1952. Advanced statistical methods in biometric research. John Wiley and Sons, Inc. (New York), 390 pp.

SNEDECOR, GEORGE W. 1956. Statistical methods applied to experiments in agriculture and biology. Fifth Edition, The Iowa State College Press (Ames), 534 pp.

TAGUCHI, KISABURO. 1957. Salmon fisheries and the resources of the North Pacific Ocean. (Revised Edition) Nichiro Gyogyo Kabushiki Kaisha (Tokyo) (Nichiro Fishing Company, Ltd.), 266 pp.

APPENDIX A. LIST OF PINK SALMON SAMPLES OBTAINED DURING 1957 AND PROCESSED FOR MORPHOLOGICAL CHARACTERISTICS.

1957 Inshore Fishery and Stream Samples.

Area	Location	Date	Sample size
Puget Sound	La Conner, Washington	9/6	102
Fraser River fishery	Gulf of Georgia	9/4	100
Rivers Inlet	—	8/13	100
Skeena River fishery	Tyee	7/30	96
Nass River fishery	Sommerville Island	8/4	92
Ketchikan	Vicinity Point Eaton	8/14	114
Petersburg	Tenakee	7/30	50
Petersburg	Windham Bay	8/8	111
Yakutat	Situk-Ahrnklin River	8/1	99
Prince William Sound	Anderson Bay	7/16	45
Prince William Sound	Anderson Bay	8/1	56
Cook Inlet	Tutka Bay	7/4	100
Kodiak Island	Uyak Bay	7/30	101
King Cove	Shumagin traps	7/11	70
King Cove	Shumagin traps	7/26	30
Northwest Alaska	Unalakleet River	7/9	99
Attu Island	Lake Nicholas	7 & 8/–	29
Attu Island	Gravel Pit	8/4	67
Attu Island	Gravel Pit	8/5	54
Attu Island	Lake Cornica	8/–	26
Attu Island	Lake Cornica	8/10	30
Hokkaido Island	Yubetsu River	9/–	100
Hokkaido Island	Shari fishery	9/–	63
Hokkaido Island	Tokoro fishery	9/–	70
Hokkaido Island	Abashiri fishery	9/–	65

1957 High-Seas Samples by Longitude.

Source	Location	Date	Sample size
MV *Key West*	55°00′ N., 135°00′ W.	7/31	16
MV *Key West*	55°00′ N., 135°00′ W.	8/1	49
MV *Key West*	55°00′ N., 145°00′ W.	7/12	88
MV *Attu*	54°00′ N., 160°00′ W.	7/15	6
MV *Attu*	53°40′ N., 165°00′ W.	7/25	24
MV *Commander*	52°00′ N., 174°20′ W. (approx)	6/6	48
MV *Attu*	50°00′ N., 175°00′ W.	5/28	17
MV *Attu*	53°00′ N., 175°00′ W.	6/8	67
MV *Attu*	53°00′ N., 175°00′ W.	6/9	88
MV *Attu*	53°00′ N., 175°00′ W.	6/10	47
MV *Pioneer*	56°00′ N., 175°00′ W.	6/29	122
MV *Pioneer*	56°00′ N., 175°00′ W.	6/30	70
MV *Pioneer*	51°00′ N., 176°00′ W.	7/8	11
MV *Commander*	51°55′ N., 176°05′ W. (approx)	6/8	60
MV *Commander*	51°50′ N., 176°20′ W. (approx)	6/20	51
MV *Pioneer*	53°00′ N., 180°00′	6/22	16
Kano Maru	50°05′ N., 179°56′ E.	6/8	53
Nippon Suisan Fisheries Co.	58°15′ N., 179°10′ E.	6/27	23
Nippon Suisan Fisheries Co.	58°10′ N., 177°17′ E.	7/1	29
MV *Pioneer*	50°00′ N., 175°00′ E.	6/10	151
MV *Pioneer*	50°00′ N., 175°00′ E.	6/11	95
MV *Pioneer*	50°00′ N., 175°00′ E.	6/12	110
MV *Pioneer*	53°00′ N., 175°00′ E.	6/14	110

Continu

Appendix A. (Continued)

Source	Location	Date	Sample size
IV *Pioneer*	53°00′ N., 175°00′ E.	6/20	226
IV *Pioneer*	56°00′ N., 175°00′ E.	7/16	17
ano Maru	49°37′ N., 171°00′ E.	6/1	37
ano Maru	49°45′ N., 170°24′ E.	5/25	30
ippon Suisan Fisheries Co.	54°51′ N., 170°24′ E.	7/6	27
ippon Suisan Fisheries Co.	57°02′ N., 169°11′ E.	7/12	39
ano Maru	49°13′ N., 169°00′ E.	5/24	23
ippon Suisan Fisheries Co.	51°41′ N., 167°27′ E.	6/28	35
ippon Suisan Fisheries Co	57°26′ N., 167°27′ E.	7/13	32
suzan Maru	49°02′ N., 167°25′ E.	5/31	105
ippon Suisan Fisheries Co.	58°12′ N., 166°48′ E.	7/15	29
suzan Maru	50°03′ N., 166°47′ E.	6/1	100
ichiro Fisheries Co.	52°33′ N., 166°04′ E.	6/20	50
ippon Suisan Fisheries Co.	51°39′ N., 162°16′ E.	7/1	35
ichiro Fisheries Co.	52°28′ N., 161°42′ E.	6/30	67
ichiro Fisheries Co.	51°39′ N., 161°40′ E.	7/20	54
ichiro Fisheries Co.	52°36′ N., 161°21′ E.	7/10	67
ippon Suisan Fisheries Co.	51°28′ N., 161°15′ E.	7/5	34
ichiro Fisheries Co.	51°22′ N., 160°15′ E.	7/22	68
ichiro Fisheries Co.	51°13′ N., 159°45′ E.	7/24	49
ippon Suisan Fisheries Co.	48°57′ N., 158°30′ E.	7/15	99
ippon Suisan Fisheries Co.	49°02′ N., 158°20′ E.	7/14	35
ippon Suisan Fisheries Co.	49°14′ N., 158°11′ E.	7/10	35
Hokkaido Fisheries Co.	52°08′ N., 154°15′ E.	6/24	92
Hokkaido Fisheries Co.	51°16′ N., 153°39′ E.	7/14	90
Hokkaido Fisheries Co.	50°52′ N., 153°28′ E.	7/4	90

APPENDIX B. INTRA-AREA VARIABILITY TESTS.

APPENDIX B-1. Results of variance ratio tests for homogeneity of variance and analysis of variance tests of the means betw sexes with chi-square tests of the combined probabilities from other than scale characters.

Total vertebrae

Locality	Date	Age	Sex	Sample size	Variance S^2	Variance F	Variance $d.f.$	Variance P	Means Mean	Means $S_{\bar{x}}$	Means F	Means $d.f.$
Kodiak Island	8/22/56	2	M	45	0.6432	1.0874	44,47	.78	69.644	0.1195	1.6136	1,91
(Karluk Weir)			F	48	0.5915				69.438	0.1110		
Northwest Alaska	7/9/56	2	M	51	0.8120	1.0043	50,47	.99	70.294	0.1262	5.9147*	1,97
(Unalakleet R.)			F	48	0.8085				69.854	0.1298		
Hokkaido Island	9/–/57	2	M	61	0.8483	1.0802	60,34	.85	69.574	0.1179	0.2082	1,94
(Yubetsu R.)			F	35	0.7853				69.486	0.1498		
Combined test					$C = -2\sum_{i=1}^{k} \log_e P_i = .842$				$C = -2\sum_{i=1}^{k} \log_e P_i = 12.018$			
					$\chi^2_{.95}(6\ d.f.) = 12.592$				$\chi^2_{.95}(6\ d.f.) = 12.592$			

* Significant at 5-percent level.

Ventral gill rakers

Locality	Date	Age	Sex	Sample size	Variance S^2	Variance F	Variance $d.f.$	Variance P	Means Mean	Means $S_{\bar{x}}$	Means F	Means $d.f.$
Kodiak Island	8/22/56	2	M	47	1.0217	1.9831*	46,46	.022	19.021	0.1474	0.1251	1,92
(Karluk Weir)			F	47	0.5152				19.085	0.1047		
Northwest Alaska	7/9/56	2	M	52	0.7980	1.1089	51,46	.76	18.788	0.1239	0.9539	1,97
(Unalakleet R.)			F	47	0.7196				18.617	0.1237		
Hokkaido Island	9/–/57	2	M	60	0.4542	2.0000**	36,59	.009	18.450	0.0870	1.0766	1,95
(Yubetsu R.)			F	37	0.9083				18.622	0.1567		
Combined test					$C = -2\sum_{i=1}^{k} \log_e P_i = 17.604$**				$C = -2\sum_{i=1}^{k} \log_e P_i = 5.283$			
					$\chi^2_{.95}(6\ d.f.) = 12.592$				$\chi^2_{.95}(6\ d.f.) = 12.592$			
					$\chi^2_{.99}(6\ d.f.) = 16.812$							

* Significant at 5-percent level.
** Significant at 1-percent level.

Total gill rakers

Locality	Date	Age	Sex	Sample size	Variance S^2	Variance F	Variance $d.f.$	Variance P	Means Mean	Means $S_{\bar{x}}$	Means F	Means $d.f.$
Kodiak Island	8/22/56	2	M	47	1.9065	1.3031	46,46	.37	30.915	0.2014	1.0676	1,92
(Karluk Weir)			F	47	1.4630				31.191	0.1764		
Northwest Alaska	7/9/56	2	M	51	2.1980	1.1369	50,45	.68	30.627	0.2076	0.0038	1,95
(Unalakleet R.)			F	46	1.9333				30.609	0.2050		
Hokkaido Island	9/–/57	2	M	60	1.1644	1.6986	36,59	.071	30.233	0.1393	1.4667	1,95
(Yubetsu R.)			F	37	1.9778				30.514	0.2312		
Combined test					$C = -2\sum_{i=1}^{k} \log_e P_i = 8.050$				$C = -2\sum_{i=1}^{k} \log_e P_i = 5.450$			
					$\chi^2_{.95}(6\ d.f.) = 12.592$				$\chi^2_{.95}(6\ d.f.) = 12.592$			

APPENDIX B–1. (Continued).

Branchiostegals

Locality	Date	Age	Sex	Sample size	Variance S^2	F	$d.f.$	P	Means Mean	$S_{\bar{x}}$	F	$d.f.$	P
dak Island	8/22/56	2	M	47	0.4391	1.0515	47,46	.89	13.319	0.0967	0.5022	1,93	.48
(Karluk Weir)			F	48	0.4617				13.417	0.0981			
rthwest Alaska	7/9/56	2	M	52	0.3157	1.5908	46,51	.11	12.365	0.0779	0.0173	1,97	.90
(Unalakleet R.)			F	47	0.5022				12.383	0.1034			
kkaido Island	9/–/57	2	M	61	0.3950	1.4276	36,60	.22	12.934	0.0805	1.1397	1,96	.29
(Yubetsu R.)			F	37	0.5639				12.784	0.1234			
Combined test					$C = -2\sum_{i=1}^{k} \log_e P_i = 7.676$				$C = -2\sum_{i=1}^{k} \log_e P_i = 4.155$				
					$\chi^2_{.95}(6\ d.f.) = 12.592$				$\chi^2_{.95}(6\ d.f.) = 12.592$				

Pectoral fin rays

Locality	Date	Age	Sex	Sample size	Variance S^2	F	$d.f.$	P	Means Mean	$S_{\bar{x}}$	F	$d.f.$	P
dak Island	8/22/56	2	M	47	0.5609	1.0337	46,47	.91	16.298	0.1092	0.0308	1,93	.86
(Karluk Weir)			F	48	0.5426				16.271	0.1063			
rthwest Alaska	7/9/56	2	M	52	0.2902	1.1144	47,51	.70	15.846	0.0747	0.0653	1,98	.80
(Unalakleet R.)			F	48	0.3234				15.875	0.0821			
kkaido Island	9/–/57	2	M	62	0.3426	1.1912	37,61	.54	16.048	0.0743	2.7377	1,98	.10
(Yubetsu R.)			F	38	0.4081				15.842	0.1036			
Combined test					$C = -2\sum_{i=1}^{k} \log_e P_i = 2.135$				$C = -2\sum_{i=1}^{k} \log_e P_i = 5.353$				
					$\chi^2_{.95}(6\ d.f.) = 12.592$				$\chi^2_{.95}(6\ d.f.) = 12.592$				

Dorsal fin rays

Locality	Date	Age	Sex	Sample size	Variance S^2	F	$d.f.$	P	Means Mean	$S_{\bar{x}}$	F	$d.f.$	P
diak Island	8/22/56	2	M	47	0.5304	1.2160	46,47	.51	15.234	0.1062	0.0000	1,93	.99
(Karluk Weir)			F	48	0.4362				15.229	0.0953			
rthwest Alaska	7/9/56	2	M	52	0.4373	1.0816	51,47	.79	15.615	0.0917	4.0427*	1,98	.048
(Unalakleet R.)			F	48	0.4043				15.354	0.0918			
kkaido Island	9/–/57	2	M	62	0.3443	1.1226	37,61	.68	15.016	0.0745	3.3611	1,98	.073
(Yubetsu R.)			F	38	0.3865				14.789	0.1085			
Combined test					$C = -2\sum_{i=1}^{k} \log_e P_i = 2.590$				$C = -2\sum_{i=1}^{k} \log_e P_i = 11.328$				
					$\chi^2_{.95}(6\ d.f.) = 12.592$				$\chi^2_{.95}(6\ d.f.) = 12.592$				

* Significant at 5-percent level.

APPENDIX B-1. (Continued).

Anal fin rays

Locality	Date	Age	Sex	Sample size	Variance S^2	Variance F	Variance $d.f.$	Variance P	Means Mean	Means $S_{\bar{x}}$	Means F	Means $d.f.$
Kodiak Island	8/22/56	2	M	47	0.2848	1.5913	47,46	.13	17.617	0.0778	2.4513	1,93
(Karluk Weir)			F	48	0.4532				17.813	0.0972		
Northwest Alaska	7/9/56	2	M	52	0.5294	1.5552	51,47	.14	18.481	0.1090	0.0000	1,98
(Unalakleet R.)			F	48	0.3404				18.479	0.0842		
Hokkaido Island	9/-/57	2	M	62	0.5902	1.2499	61,36	.47	18.000	0.0976	1.1153	1,97
(Yubetsu R.)			F	37	0.4722				17.838	0.1130		
Combined test					$C = -2\sum_{i=1}^{k} \log_e P_i = 9.523$				$C = -2\sum_{i=1}^{k} \log_e P_i = 6.736$			
					$\chi^2_{.95}(6\ d.f.) = 12.592$				$\chi^2_{.95}(6\ d.f.) = 12.592$			

APPENDIX B-2. Results of variance ratio tests for homogeneity of variance and analysis of variance tests of the means betwe sexes with chi-square tests of the combined probabilities in scale characters.

Number of circuli

Locality	Date	Age	Sex	Sample size	Variance S^2	Variance F	Variance $d.f.$	Variance P	Means Mean	Means $S_{\bar{x}}$	Means F	Means $d.f.$
Northwest Alaska	7/9/56	2	M	43	2.1190	1.2231	36,42	.55	21.977	.2220	0.5192	1,78
(Unalakleet R.)		2	F	37	2.5917				21.730	.2646		
Hokkaido Island	9/-/57	2	M	39	5.5105	1.0327	38,25	.47	27.744	.3759	0.4826	1,63
(Yubetsu R.)		2	F	26	5.3360				28.154	.4530		
Combined test					$C = -2\sum_{i=1}^{k} \log_e P_i = 1.256$				$C = -2\sum_{i=1}^{k} \log_e P_i = 2.894$			
					$\chi^2_{.95}(4\ d.f.) = 9.488$				$\chi^2_{.95}(4\ d.f.) = 9.488$			

Scale length

Locality	Date	Age	Sex	Sample size	Variance S^2	Variance F	Variance $d.f.$	Variance P	Means Mean	Means $S_{\bar{x}}$	Means F	Means $d.f.$
Northwest Alaska	7/9/56	2	M	43	16.5810	1.0005	36,42	.99	38.884	.6210	0.1891	1,78
(Unalakleet R.)		2	F	37	16.5889				38.486	.6695		
Hokkaido Island	9/-/57	2	M	39	33.8158	1.2387	38,25	.58	53.974	.9312	0.1123	1,63
(Yubetsu R.)		2	F	26	27.3000				53.500	1.0247		
Combined test					$C = -2\sum_{i=1}^{k} \log_e P_i = 1.110$				$C = -2\sum_{i=1}^{k} \log_e P_i = 1.402$			
					$\chi^2_{.95}(4\ d.f.) = 9.488$				$\chi^2_{.95}(4\ d.f.) = 9.488$			

Appendix B-2. (Continued).

Intermediate zone

Locality	Date	Age	Sex	Sample size	Variance S^2	Variance F	Variance $d.f.$	Variance P	Means Mean	Means $S_{\bar{x}}$	Means F	Means $d.f.$	Means P
west Alaska	7/9/56	2	M	43	2.9468	1.0096	42,36	.98	16.6512	.2617	0.2417	1,78	.62
alakleet R.)		2	F	37	2.9189				17.4324	.2809			
ido Island	9/–/57	2	M	39	3.1500	1.5010	25,38	.29	18.487	.2842	3.1398	1,63	.081
betsu R.)		2	F	26	4.7280				17.615	.4264			
bined test					$C = -2\sum_{i=1}^{k} \log_e P_i = 2.516$				$C = -2\sum_{i=1}^{k} \log_e P_i = 5.983$				
					$\chi^2_{.95}(4\ d.f.) = 9.488$				$\chi^2_{.95}(4\ d.f.) = 9.488$				

Appendix B-3. Correlation of characters with length of fish, chi-square tests for common correlation, average r and average r^2.

Locality	Date	Sample size	Total vertebrae r	Ventral gill rakers r	Total gill rakers r	Branchio-stegals r	Pectoral fin rays r	Dorsal fin rays r	Anal fin rays r
sland (Gravel Pit)	8/–/55	74	−0.0242	0.0851	0.0822	0.0159	−0.1794	0.1608	0.1359
s(River (Sweltzer Creek)	11/2/55	47	0.0318	0.0118	0.1295	−0.0472	−0.2205	−0.1549	−0.1024
aska Island (Unalaska Cr.)	8/17/55	33	−0.0096	−0.0263	0.0687	0.1908	−0.0462	0.0317	0.0432
k Island (Karluk Weir)	8/22/56	92	0.1501	0.1444	0.1452	0.1198	0.0525	0.1440	0.0991
River (Lakelse Lake)	10/26/56	50	−0.2923	−0.2290	−0.2425	−0.1248	−0.0918	−0.1240	−0.1764
aska Island (Shaisnikoff R.)	8/11/56	43	−0.1366	0.1817	0.2049	0.0752	−0.1017	0.1814	−0.0455
aska Island (Nanteeken R.)	8/23/56	45	0.0069	0.0202	0.1574	−0.3181	−0.0967	0.1402	0.0904
west Alaska (Unalakleet R.)	7/9/56	95	0.2087	0.0571	0.0460	0.1152	−0.0293	−0.0189	0.1359
Island (Gravel Pit)	8/4/57	64	−0.0126	0.0686	0.0730	0.0264	−0.0583	0.2080	0.1838
Island (Gravel Pit)	8/5/57	52	−0.1174	0.1076	0.1251	−0.1041	0.1114	0.1872	0.0642
Island (Lake Cornica)	8/10/57	30	−0.2776	−0.0032	0.0616	−0.0906	−0.0503	0.0538	−0.4105
kaido Island (Yubetsu R.)	9/–/57	91	0.0070	0.0638	−0.0489	0.1445	−0.0393	−0.0047	0.2293
χ^2	=		14.159	5.925	7.921	11.567	5.085	9.046	15.668
$\chi^2_{.95}(11\ d.f.)$	=		19.675	19.675	19.675	19.675	19.675	19.675	19.675
Average r	=		−0.0010	0.0532	0.0620	0.0241	−0.0550	0.0696	0.0657
Average r^2	=		0.000001	0.0028	0.0038	0.0006	0.0030	0.0048	0.0043
cent variation attributable o length	=		0.0001%	0.28%	0.38%	0.06%	0.30%	0.48%	0.43%

Appendix B-4. Correlation of scale characters with length of fish, chi-square tests for common correlation, average r and average r^2.[1]

Locality	Date	Sample size	No. of circuli r	Scale length r	Intermediate zone r
Unalaska Island (Shaisnikoff R.)	8/11/56	26	0.2584	0.0484	0.0173
ttu Island (Gravel Pit)	8/4/57	57	0.2213	0.2704	0.0811
ttu Island (Gravel Pit)	8/5/57	47	0.2130	0.2864	0.0525
Northwest Alaska (Unalakleet R.)	7/9/56	80	0.2424	0.3591	0.1688
Hokkaido Island (Yubetsu R.)	9/–/57	65	0.1734	0.3965	0.1548
Attu Island (Lake Cornica)	8/10/57	27	0.1812	0.1026	−0.2429
χ^2	=		0.261	3.739	3.685
$\chi^2_{.95}(5\ d.f.)$	=		11.070	11.070	11.070
Average r	=		0.2149**	0.2954**	0.0841**
Average r^2	=		0.0462	0.0873	0.0071
Percent variation attributable to length	=		4.62%	8.73%	0.71%

** Significant at 1-percent level.

[1] Reduced number of samples from those of Table 4 due to absorbed scales.

APPENDIX C.

APPENDIX C–1. Tests for differences between the samples pooled in composing the Karaginskii and Kodiak-Cook Inlet morphotypes.

KODIAK-COOK INLET MORPHOTYPE

Total vertebrae

Area	Sample size (n)	$\Sigma\chi$	$\Sigma\chi^2$	Corr. Sum Sq.	n–1	S^2	Variance ra
Kodiak Island	87	5,936	405,066	53.4023	86	0.6210	F=1.2628
Cook Inlet	80	5,482	375,716	61.9500	79	0.7842	
	167	11,418	780,782	115.3523		$F_{.01}(79,86)$=1.68	
Total	780,782.0000−780,663.0180=118.9820			166 *d.f.*			
Btw.	780,666.6477−780,663.0180= 3.6297			1 *d.f.*	3.6297		
			115.3523	165 *d.f.*	0.6991 = 5.1920 = F	$F_{.01}(1,165)$=6.79	

Dorsal fin rays

Area	Sample size (n)	$\Sigma\chi$	$\Sigma\chi^2$	Corr. Sum Sq.	n–1	S^2	Variance rat
Kodiak Island	87	1,281	18,907	45.3793	86	0.5277	F=1.0288
Cook Inlet	80	1,197	17,953	42.8875	79	0.5429	
	167	2,478	36,860	88.2668		$F_{.01}(79,86)$=1.68	
Total	36,860.0000−36,769.3653=90.6347			166 *d.f.*			
Btw.	36,771.7332−36,769.3653= 2.3679			1 *d.f.*	2.3679		
			88.2668	165 *d.f.*	0.5350 = 4.4260 = F	$F_{.01}(1,165)$=6.79	

Scale length of intermediate zone

Area	Sample size (n)	$\Sigma\chi$	$\Sigma\chi^2$	Corr. Sum Sq.	n–1	S^2	Variance rat
Kodiak Island	87	1,566	28,494	306.0000	86	3.5581	F=1.0130
Cook Inlet	80	1,451	26,595	277.4875	79	3.5125	
	167	3,017	55,089	583.4875		$F_{.01}(86,79)$=1.68	
Total	55,089.0000−54,504.7246=584.2754			166 *d.f.*			
Btw.	54,505.5125−54,504.7246= 0.7879			1 *d.f.*	0.7879		
			583.4875	165 *d.f.*	3.5363 = .2228 = F	$F_{.01}(1,165)$=6.79	

Appendix C-1. (Continued).

araginskii Morphotype

Total vertebrae

rea	Sample size (n)	$\Sigma\chi$	$\Sigma\chi^2$	Corr. Sum Sq.	n-1	S^2	$\log_e S^2$	Chi-square
′ N., 169°11′ E.	27	1,864	128,706	20.9630	26	0.8063	−0.21530	
′ N., 167°27′ E.	26	1,804	125,192	22.1538	25	0.8862	−0.12081	
′ N., 166°48′ E.	21	1,453	100,559	25.2381	20	1.2619	0.23261	
	74	5,121	354,457	68.3549	71	0.9627	−0.03801	1.26714
						$\chi^2_{.01}(2\ d.f.)=9.210$		

Total	354,457.0000−354,387.0405=69.9595	73 *d.f.*			
Betw.	354,388.6451−354,387.0405= 1.6046	2 *d.f.*	0.8023		
	68.3549	71 *d.f.*	0.9627	$=0.8334=F$	$F_{.01}(2,71)=4.92$

Dorsal fin rays

Area	Sample size (n)	$\Sigma\chi$	$\Sigma\chi^2$	Corr. Sum Sq.	n-1	S^2	$\log_e S^2$	Chi-square
′ N., 169°11′ E.	27	405	6,091	16.0000	26	0.6154	−0.48548	
′ N., 167°27′ E.	26	394	5,984	13.3846	25	0.5354	−0.62474	
′ N., 166°48′ E.	21	317	4,795	9.8095	20	0.4905	−0.71234	
	74	1,116	16,870	39.1941	71	0.5520	−0.59421	0.29887
						$\chi^2_{.01}(2\ d.f.)=9.210$		

Total	16,870.0000−16,830.4865=39.5135	73 *d.f.*			
Betw.	16,830.8059−16,830.4865= 0.3194	2 *d.f.*	0.1597		
	39.1941	71 *d.f.*	0.5520	$=0.2893=F$	$F_{.01}(2,71)=4.92$

Scale length of intermediate zone

Area	Sample size (n)	$\Sigma\chi$	$\Sigma\chi^2$	Corr. Sum Sq.	n-1	S^2	$\log_e S^2$	Chi-square
′ N., 169°11′ E.	27	525	10,307	98.6667	26	3.7949	1.33366	
′ N., 167°27′ E.	26	496	9,538	75.8462	25	3.0338	1.10981	
′ N., 166°48′ E.	21	403	7,849	115.2381	20	5.7619	1.75127	
	74	1,424	27,694	289.7510	71	4.0810	1.40635	2.40504
						$\chi^2_{.01}(2\ d.f.)=9.210$		

Total	27,694.0000−27,402.3784=291.6216	73 *d.f.*			
Betw.	27,404.2491−27,402.3784= 1.8707	2 *d.f.*	0.9354		
	289.7509	71 *d.f.*	4.0814	$=0.2292=F$	$F_{.01}(2,71)=4.92$

Appendix C-2. Bivariate frequency distributions and tests for linearity of regression between all pairs of morphological characters used for racial separation of 1957 pink salmon according to Dixon and Massey, 1957.

Pertinent Values for Computations

Karaginskii Morphotype	*Sample size*	*Sum*	*Sum of squares*
Dorsal fin rays	74	1116	16870
Intermediate scale zone length	74	1424	27694
Total vertebrae	74	5121	354457
Cross products			
Sum of dorsal fin rays with intermediate scale zone lengths			=21477
Sum of dorsal fin rays with total vertebrae			=77239
Sum of intermediate scale zone lengths with total vertebrae			=98543

Kodiak-Cook Inlet Morphotype	*Sample size*	*Sum*	*Sum of squares*
Dorsal fin rays	167	2478	36860
Intermediate scale zone length	167	3017	55089
Total vertebrae	167	11418	780782
Cross products			
Sum of dorsal fin rays with intermediate scale zone lengths			=44764
Sum of dorsal fin rays with total vertebrae			=169431
Sum of intermediate scale zone lengths with total vertebrae			=206256

APPENDIX C–2. (Continued).

Karaginskii Morphotype: Bivariate frequency distribution of dorsal fin ray counts and intermediate scale zone lengths.

	Dorsal fin rays						
Int.	13	14	15	16	17	Freq.	f(D.F.R.)
14			1			1	15
15			1			1	15
16			2			2	30
17		2	9	2		13	195
18		4	3	2	1	10	150
19		2	9	3	1	15	228
20		1	3	4		8	123
21		3	8	3		14	210
22	1		4	2		7	105
23			3			3	45
Freq.	1	12	43	16	2	74	1116
f(Int.)	22	227	824	314	37	1424	

e with intermediate scale zone lengths as the independent variable (X) and dorsal fin ray counts as the dependent variable (Y).

ıms of squares	Corr. sums of squares	Degrees of freedom	Mean squares
ithin groups	$16870.0000 - 16831.7250 = 38.2750$	$74 - 10 = 64$	0.5980
ɔtal	$16831.7250 - 16830.4865 = 1.2385$	9	
egression	$b^2(27694.0000 - 27402.3784 = 291.6216)$		
	$\frac{(1.5406)^2}{(291.6216)^2} \quad (291.6216) = 0.0081$	1	
bout regression	$= \text{Total} - \text{regression} = 1.2304$	8	0.1538
	$F = \frac{0.1538}{0.5980} = 0.2572 \qquad F_{.01}(8,64) = 2.79$		

ecision: Accept hypothesis regression line is straight line.

with dorsal fin ray counts as the independent variable (X) and intermediate scale zone lengths as the dependent variable (Y).

ums of squares	Corr. sums of squares	Degrees of freedom	Mean squares
Within groups	$27694.0000 - 27414.9729 = 279.0271$	$74 - 5 = 69$	4.0439
otal	$27414.9729 - 27402.3784 = 12.5945$	4	
egression	$b^2(16870.0000 - 16830.4865 = 39.5135)$		
	$\frac{(1.5406)^2}{(39.5135)^2} \quad (39.5135) = 0.0601$	1	
bout regression	$= \text{Total} - \text{regression} = 12.5344$	3	4.1781
	$F = \frac{4.1781}{4.0439} = 1.0332 \qquad F_{.01}(3,69) = 4.08$		

ecision: Accept hypothesis regression line is straight line.

APPENDIX C–2. (Continued).

Karaginskii Morphotype: Bivariate frequency distribution of dorsal fin ray counts and total vertebrae counts.

	Dorsal fin rays						
Total vertebrae	13	14	15	16	17	Freq.	f(D.F.R.)
67			1			1	15
68		3	10	1		14	208
69		6	23	7	1	37	558
70	1	2	7	6		16	242
71			1	1	1	3	48
72		1	1	1		3	45
Freq.	1	12	43	16	2	74	1116
f(T.V.)	70	830	2967	1114	140	5121	

Test with dorsal fin ray counts as the independent variable (X) and total vertebrae counts as the dependent variable (Y

Sums of squares	Corr. sums of squares	Degrees of freedom	Mean square
Within groups	$354457.0000 - 354393.5833 = 63.4167$	$74-5=69$	0.9191
Total	$354393.5833 - 354387.0405 = 6.5428$	4	
Regression	$b^2(16870.0000 - 16830.4865 = 39.5135)$		
	$\frac{(8.7838)^2}{(39.5135)^2}(39.5135) = 1.9526$	1	
About regression	= Total − regression = 4.5902	3	1.5301
	$F = \frac{1.5301}{0.9191} = 1.6648 \qquad F_{.01}(3,69) = 4.08$		
Decision: Accept hypothesis regression line is straight line.			

Test with total vertebrae counts as the independent variable (X) and dorsal fin ray counts as the dependent variable (Y

Sums of squares	Corr. sums of squares	Degrees of freedom	Mean square
Within groups	$16870.0000 - 16833.7790 = 36.2210$	$74-6=68$	0.5327
Total	$16833.7790 - 16830.4865 = 3.2925$	5	
Regression	$b^2(354457.0000 - 354387.0405 = 69.9595)$		
	$\frac{(8.7838)^2}{(69.9595)^2}(69.9595) = 1.1028$	1	
About regression	= Total − regression = 2.1897	4	0.5474
	$F = \frac{0.5474}{0.5327} = 1.0276 \qquad F_{.01}(4,68) = 3.61$		
Decision: Accept hypothesis regression line is straight line.			

APPENDIX C-2. (Continued).

Karaginskii Morphotype: Bivariate frequency distribution of total vertebrae counts and intermediate scale zone lengths.

	Total vertebrae							
Int.	67	68	69	70	71	72	Freq.	f(T.V.)
14			1				1	69
15			1				1	69
16			1	1			2	139
17	1	1	5	5	1		13	901
18		3	4	2	1		10	691
19		3	10	1		1	15	1036
20		1	5	1		1	8	555
21		3	7	2	1	1	14	970
22		2	2	3			7	484
23		1	1	1			3	207
Freq.	1	14	37	16	3	3	74	5121
f(Int.)	17	278	706	307	56	60	1424	

: with total vertebrae counts as the independent variable (X) and intermediate scale zone lengths as the dependent variable (Y).

Sums of squares	Corr. sums of squares	Degrees of freedom	Mean squares
Within groups	$27694.0000-27416.4248 = 277.5752$	$74-6 = 68$	4.0820
Total	$27416.4248-27402.3784 = 14.0464$	5	
Regression	$b^2(354457.0000-354387.0405 = 69.9595)$		
	$\frac{(-1.6486)^2}{(69.9595)^2}(69.9595) = 0.0388$	1	
About regression	= Total − regression = 14.0076	4	3.5019
	$F = \frac{3.5019}{4.0820} = 0.8579 \qquad F_{.01}(4,68) = 3.61$		

Decision: Accept hypothesis regression line is straight line.

t with intermediate scale zone lengths as the independent variable (X) and total vertebrae counts as the dependent variable (Y).

Sums of squares	Corr. sums of squares	Degrees of freedom	Mean squares
Within groups	$354457.0000-354388.3081 = 68.6919$	$74-10 = 64$	1.0733
Total	$354388.3081-354387.0405 = 1.2676$	9	
Regression	$b^2(27694.0000-27402.3784 = 291.6216)$		
	$\frac{(-1.6486)^2}{(291.6216)^2}(291.6216) = 0.0093$	1	
About regression	= Total − regression = 1.2583	8	0.1573
	$F = \frac{0.1573}{1.0733} = 0.1466 \qquad F_{.01}(8,64) = 2.79$		

Decision: Accept hypothesis regression line is straight line.

APPENDIX C-2. (Continued).

Kodiak-Cook Inlet Morphotype: Bivariate frequency distribution of dorsal fin ray counts and intermediate scale zone lengths.

	Dorsal fin rays					
Int.	13	14	15	16	Freq.	f(D.F.R.)
13				1	1	16
14			2	1	3	46
15		4	2	1	7	102
16	1	7	12	5	25	371
17	1	12	9	6	28	412
18		12	23	6	41	609
19		5	13	2	20	297
20	1	7	11	8	27	404
21		2	5	1	8	119
22		2	4		6	88
23		1			1	14
Freq.	3	52	81	31	167	2478
f(Int.)	53	936	1477	551	3017	

Test with intermediate scale zone lengths as the independent variable (X) and dorsal fin ray counts as the dependent variable (Y).

Sums of squares	Corr. sums of squares	Degrees of freedom	Mean squares
Within groups	$36860.0000 - 36773.7015 = 86.2985$	$167 - 11 = 156$	0.5532
Total	$36773.7015 - 36769.3653 = 4.3362$	10	
Regression	$b^2(55089.0000 - 54504.7246 = 584.2754)$		
	$\frac{(-3.2216)^2}{(584.2754)^2} (584.2754) = 0.0178$	1	
About regression	= Total − regression = 4.3184	9	0.4798
	$F = \frac{0.4798}{0.5532} = 0.8673 \qquad F_{.01}(9,156) = 2.53$		

Decision: Accept hypothesis regression line is a straight line.

Test with dorsal fin ray counts as the independent variable (X) and intermediate scale zone lengths as the dependent variable (Y).

Sums of squares	Corr. sums of squares	Degrees of freedom	Mean squares
Within groups	$55089.0000 - 54510.3708 = 578.6292$	$167 - 4 = 163$	3.5499
Total	$54510.3708 - 54504.7246 = 5.6462$	3	
Regression	$b^2(36860.0000 - 36769.3653 = 90.6347)$		
	$\frac{(-3.2216)^2}{(90.6347)^2} (90.6347) = 0.1145$	1	
About regression	= Total − regression = 5.5317	2	2.7658
	$F = \frac{2.7658}{3.5499} = 0.7791 \qquad F_{.01}(2,163) = 4.75$		

Decision: Accept hypothesis regression line is a straight line.

APPENDIX C-2. (Continued).

Kodiak-Cook Inlet Morphotype: Bivariate frequency distribution of dorsal fin ray counts and total vertebrae counts.

	Dorsal fin rays					
Total vertebrae	13	14	15	16	Freq.	f(D.F.R.)
66		1		1	2	30
67		8	10		18	262
68	2	25	35	17	79	1173
69		14	27	11	52	777
70	1	4	9	2	16	236
Freq.	3	52	81	31	167	2478
f(T.V.)	206	3548	5543	2121	11418	

st with dorsal fin ray counts as the independent variable (X) and total vertebrae counts as the dependent variable (Y).

Sums of squares	Corr. sums of squares	Degrees of freedom	Mean squares
Within groups	780782.0000 − 780664.6776 = 117.3224	167 − 4 = 163	0.7198
Total	780664.6776 − 780663.0180 = 1.6596	3	
Regression	b^2(36860.0000 − 36769.3653 = 90.6347)		
	$\frac{(7.0240)^2}{(90.6347)^2}$ (90.6347) = 0.5443	1	
About regression	= Total − regression = 1.1153	2	0.5576
	$F = \frac{0.5576}{0.7198} = 0.7746$ $F_{.01}(2,163) = 4.75$		

Decision: Accept hypothesis regression line is a straight line.

est with total vertebrae counts as the independent variable (X) and dorsal fin ray counts as the dependent variable (Y).

Sums of squares	Corr. sums of squares	Degrees of freedom	Mean squares
Within groups	36860.0000 − 36771.5514 = 88.4486	167 − 5 = 162	0.5460
Total	36771.5514 − 36769.3653 = 2.1861	4	
Regression	b^2(780782.0000 − 780663.0180 = 118.9820)		
	$\frac{(7.0240)^2}{(118.9820)^2}$ (118.9820) = 0.4146	1	
About regression	= Total − regression = 1.7715	3	0.5905
	$F = \frac{0.5905}{0.5460} = 1.0815$ $F_{.01}(3,162) = 3.91$		

Decision: Accept hypothesis regression line is a straight line.

APPENDIX C-2. (Continued).

Kodiak-Cook Inlet Morphotype: Bivariate frequency distribution of total vertebrae counts and intermediate scale zone lengths.

	Total vertebrae						
Int.	66	67	68	69	70	Freq.	f(T.V.)
13				1		1	69
14				2	1	3	208
15		1	4	2		7	477
16		1	14	8	2	25	1711
17	1	3	9	11	4	28	1918
18	1	5	19	14	2	41	2799
19		4	9	5	2	20	1365
20		1	19	5	2	27	1844
21		1	3	3	1	8	548
22		1	2	1	2	6	412
23		1				1	67
Freq.	2	18	79	52	16	167	11418
f(Int.)	35	334	1437	918	293	3017	

Test with total vertebrae counts as the independent variable (X) and intermediate scale zone lengths as the dependent variable (Y

Sums of squares	Corr. sums of squares	Degrees of freedom	Mean squares
Within groups	55089.0000 − 54520.6969 = 568.3031	167 − 5 = 162	3.5080
Total	54520.6969 − 54504.7246 = 15.9723	4	
Regression	b^2(780782.0000 − 780663.0180 = 118.9820)		
	$\frac{(-20.0838)^2}{(118.9820)^2}$ (118.9820) = 3.3901	1	
About regression	= Total − regression = 12.5822	3	4.1941
	$F = \frac{4.1941}{3.5080} = 1.1956$ $F_{.01}(3,162) = 3.91$		

Decision: Accept hypothesis regression line is a straight line.

Test with intermediate scale zone lengths as the independent variable (X) and total vertebrae counts as the dependent variable (Y

Sums of squares	Corr. sums of squares	Degrees of freedom	Mean squares
Within groups	780782.0000 − 780670.5544 = 111.4456	167 − 11 = 156	0.7144
Total	780670.5544 − 780663.0180 = 7.5364	10	
Regression	b^2(55089.0000 − 54505.7246 = 584.2754)		
	$\frac{(-20.0838)^2}{(584.2754)^2}$ (584.2754) = 0.6904	1	
About regression	= Total − regression = 6.8460	9	0.7607
	$F = \frac{0.7607}{0.7144} = 1.0648$ $F_{.01}(9,156) = 2.53$		

Decision: Accept hypothesis regression line is a straight line.

tures, there is a distinct possibility that red
n from North American areas other than
Bay may occur in the area. Past analyses
shown that using this particular discriminant
on, these would be misclassified as Kamchatkan
n. Alternative analyses must be used to provide
nation on the origin of these immature stocks
to interpreting results of immature classification
discriminant function analysis.

. Deficiencies in sampling are evident in the
y of samples from the western Bering Sea and
ay and June from the North Pacific Ocean,
ng present knowledge of the distribution in the
eas of Kamchatkan and western Alaskan stocks
d salmon. Although samples containing a
minance of matures taken after certain times
e reasonably used as the Kamchatkan reference
hotypes, the desirability of having stream
es is obvious.

Literature Cited

ara, Francis M., Sueto Murai, John J. LaLanne and Arporna Sribhibhadh. 1959. Use of morphological differences in determining the area of origin of red salmon taken on the high seas. Bureau of Commercial Fisheries, Biological Laboratory, Seattle, Washington (INPFC Doc. 397). 161 p. October 14, 1959. Processed.

Fukuhara, Francis M. 1960. Analysis of red salmon morphological data. *In:* Progress report of investigations by the United States during 1960, p. 67–90. Biological Laboratory, Bureau of Commercial Fisheries, Seattle, Washington (INPFC Doc. 420). Oct. 12, 1960. Processed.

International North Pacific Fisheries Commission. 1960. Proceedings of the Seventh Annual Meeting, International North Pacific Fisheries Commission, 1960. 284 p.

Ishida, Feruo, and Kiichi Miyaguchi. 1958. On the maturity of Pacific salmon (*Oncorhynchus nerka*, *O. keta* and *O. gorbuscha*) in offshore waters, with reference to the seasonal variation in gonad weight. *Bulletin, Hokkaido Regional Fisheries Research Laboratory* (Yoichi, Japan), No. 18, p. 11–22. In Japanese, with English summary. (Translation by Kunio Yonezawa, 7 p., Fisheries Research Board of Canada, Translation Series No. 190.)

Royce, William F. 1961. Forecasting salmon runs. *In:* Research in fisheries 1960, edited by Ted S. Y. Koo, p. 23–24. *College of Fisheries, University of Washington* (Seattle), *Contribution*, No. 116, March 1961.

RED SALMON SCALE STUDIES

by Raymond E. Anas

d or sockeye salmon are widely distributed in
northern Pacific Ocean. Tagging, parasito-
al and morphological studies have shown that
ring fish from Asia and North America inter-
le in the area north and south of the Aleutian
ds and that the North American red salmon in
area are predominantly from Bristol Bay. The
lem to be solved by fishery scientists is to deter-
the continent of origin of salmon caught on the
seas with a known precision.

ale studies are one technique that has been used
identifying the continent of origin of salmon
n at sea. Advantages of using scales are that
are relatively inexpensive to collect and process.
ous methods employing scales have been devel-
and show promise of distinguishing Asian from
ol Bay red salmon. However, the application
cale characters has been questioned owing to
equate studies, in most cases, of factors that
d affect the precision and reliability of continental
ration. We have studied some of the factors
could affect precision, and the results of these
ies are summarized in this report.

Adequate samples are needed to determine scale character values that are representative of specific areas. For example, a sample from a Bristol Bay river could be taken and scale character values could be compared for fish having different ages. If scale character values change depending on the age of the fish, and if this affects its classification as Asian or from Bristol Bay, then fish of each age must be considered separately. As a consequence, larger samples would be required to determine scale character values representative of Asian and Bristol Bay fish, because each age group would need its own estimate. Fish caught at sea would also need to be considered by age group; the sampling problem for these is even more difficult than for the inshore samples.

Scales have ridges or circuli on their surface that are used by biologists to determine how long a fish has lived and also to determine where it was hatched. The spacing of the circuli is used to determine the age; the spacing of circuli, number of circuli, scale length, and ratios using circuli counts and scale lengths are used to determine the continent of origin. Structurally, salmon scales begin as a small central

nternational North Pacific Fisheries Commission, Annual Report 1961,
ancouver, Canada, 1963, p. 114-116.

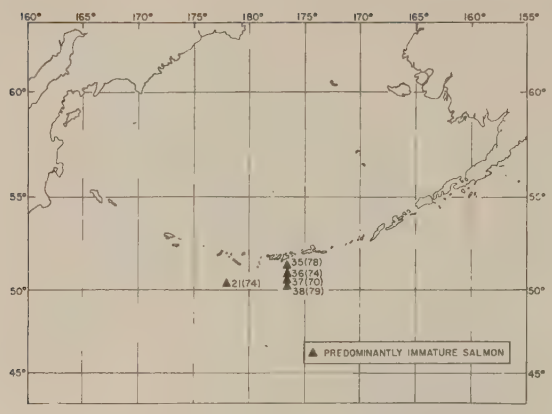


FIGURE 26. Percentage of samples classified western Alaskan type—August, 1960. First number indicates sample number; second number percent western Alaskan type.

August.—Only five samples were utilized from the August collection, all of which were obtained in the central Aleutian region with four of these taken in a rather narrow band along 176°30′W. longitude (see Fig. 26). The point estimates of Bristol Bay morphotype in these samples ranged from 70 to 79 percent.

SUMMARY AND CONCLUSIONS OF CLASSIFICATION ANALYSIS

1. The 1960 high seas samples were classified as being of Kamchatkan or Bristol Bay origin using the discriminant function constructed on the basis of the 1956 collections but with the average error of misclassification of Bristol Bay salmon weighted by the relative abundance of the component stocks based on the 1960 escapement estimates.

2. In the light of a very large run of red salmon to Bristol Bay, it was expected that large areas in the ocean, particularly the Bering Sea east of 180° longitude, would be almost completely dominated by mature Bristol Bay red salmon. In agreement with this expectation, all samples taken east of 180° longitude showed an overwhelming dominance of Bristol Bay morphotype (average point estimate greater than 90 percent) with the upper 90 percent confidence limit averaging about 104 percent and the lower limit averaging about 79 percent.

3. In the North Pacific Ocean in May and June (Fig. 24) mature Bristol Bay red salmon predominated east of 179°59′E. longitude by percentages ranging from 59 to 100 percent. West of 172° E. longitude Kamchatkan red salmon predominated by percentages ranging from 60 to 100 percent in samples of ma mature salmon.

4. The general trends in the east-west distribu of Kamchatkan and Bristol Bay stocks in both Bering Sea and North Pacific Ocean are similar the years 1956 through 1960. To illustrate this average percentages of western Alaska morphot in samples taken in the high seas in May and Jun 1956 through 1960 are plotted in Figure 27 in degree intervals of longitude.

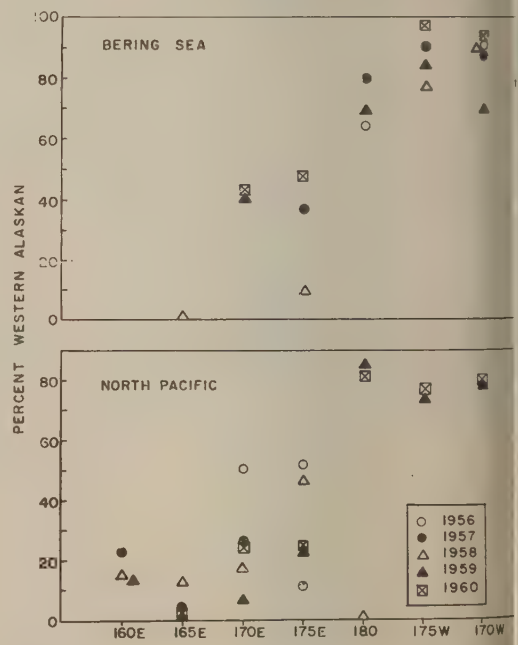


FIGURE 27. Average percentages of western Alaska morph type in samples taken in the Bering Sea and No Pacific Ocean in late May and June, 1956–1960.

5. Bristol Bay morphotype dominated all sam of immatures to 172°50′E. longitude in July August. As in past years, the degree to which Bri Bay red salmon dominate is not as pronounced immature samples as in samples dominated matures. This may be attributable to the fact when sampling takes place, the matures could more segregated during migration. A further poss explanation may be that given in item 6.

6. It was assumed in this (and previous sification analyses) that only Bristol Bay and K chatkan red salmon occur in the Bering Sea North Pacific Ocean west of the Alaskan Penins This assumption has been tenably justified for ma ing salmon but not for immatures. Although t has been little evidence to negate the hypothesis

a: and the circuli form concentrically around this a: as the scale grows. Since the central plate is mon to all scales, it can be used as a starting point etermine scale characters and factors that could f t scale character values.

Using the central plate as a focus, radii can be wn at different angles across a scale and scale racter determinations can be made on lines at e angles. The question arises, however—are character values different depending on the scale e that is used? If scale character values do nge when determined at different angles, and if affects assignment to continent of origin, then the e angle used to determine scale character values uld be consistent. The first step in testing scale es is to see if a consistent axis of the scale can be en. This is important because the precision of ting any particular angle of the scale must be wn before the data can be considered reliable. It determined that the freshwater axis (which was sen by visually dividing the freshwater zone of the e into two equal parts and using the mid-line as axis) could be selected with a precision that did introduce significant error in the scale character ues. Therefore, the freshwater axis was used to blish the selected scale angle. It was found that e character values differ greatly for a single scale n these values are taken along different radii. refore it is necessary to establish precisely the le of examination.

ed salmon ages are determined visually by per- nel trained to interpret the spacing of the circuli the scale. The accuracy of ages derived from e reading cannot be known without supplementary rmation such as tagging or marking experiments, a test of the consistency of age determinations is sible. Scales from 180 red salmon were examined three trained personnel separately and age deter- nations made. A conference was held by the same ee persons to derive an "agreed" age for all es. Using the "agreed" ages, the average error age determination was 13 percent per reader. is difference did not affect circuli counts or meas- ments of the total freshwater or first ocean zones.

Scales taken from different body locations might y in scale character values and in apparent age ause they are not all formed at the same time. To t this possible source of variation, a fish from the knek River was selected. From a chosen scale in Figure 28) it was determined that this fish had grated seaward in the third year of life and returned spawn in the sixth year. Some scales taken in

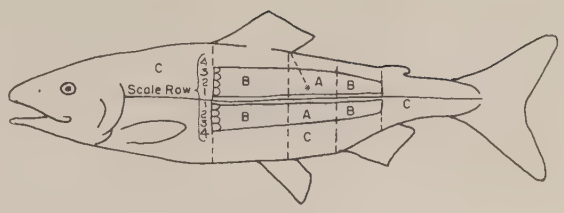


FIGURE 28. Scale sampling code used by agencies of the INPFC. A* is the preferred scale.
A—preferred area if preferred scale is missing.
B—second choice if scales in area "A" are missing.
C—all other scales.
Scales may be taken from either side of the fish, but left side is preferred. (From Proceedings of the 1957 Annual Meeting, INPFC, p. 73.)

body area C (Figure 28) above the anal fin and by the pectoral fin indicated the fish had migrated seaward in the second year and returned to spawn in the fifth year. This suggests that all scales from the same fish do not give the same age reading and that body-zone-C scales taken below the lateral line are questionable for age determinations. Area A and area B scales were tested for the scale characters, and it was found that only area A scales should be used. Consequently we have used only body-zone-A scales for determining scale characters.

Because mature males are usually larger than mature females of the same age, it was considered possible that the variation in body size might be reflected in the scale. However, tests of scale characters showed no difference between males and females for circuli counts and measurements of the first and second year freshwater zones, the total freshwater zone and the first year in the ocean zone. Ratios of circuli counts of these zones were not different between males and females. Characters computed from the ratio of freshwater zone radius to the radius of the scale (after one and two years at sea) were different between sexes.

Intra-seasonal differences were tested by using samples collected on different dates from individual Bristol Bay streams. No differences were found for any of the scale characters. Marked differences have been noted in the scale patterns of red salmon which were taken from different parts of the run of rivers other than those of Bristol Bay.

Individual red salmon spend different amounts of time in fresh water before migrating seaward. When scale samples were separated according to the number of years spent in fresh water and the presence or absence of rapid growth just prior to seaward migra-

tion, the numbers of circuli and width of the zones were found to differ for the freshwater portions of the scales. However, the width of the zone which was deposited during the first year at sea was found to be free from this difficulty. Fish with different freshwater ages should be considered separately for all other scale characters because the scale character values are significantly different depending on the freshwater age. Such groups can not be combined. This required that separate systems be developed for each group if freshwater zones of the scales are to be used to identify the origins of fish taken at sea.

From one to four years are spent at sea, with most of the maturing fish having either two or three zones on their scales (each zone represents one year of ocean residence). Tests of this source of variation show that only the width of the total freshwater zone can be used to determine the origins of high seas samples containing fish of different ocean ages. To use other characters, the samples should first be separated according to the number of years spent at sea.

If a single discriminant is to be appropriate for identifying the origin of salmon found at sea, the scale characters used must be constant for successive brood years. Fish of different brood years are mixed both at sea and in the spawning runs, so this source of variation cannot be ignored. No scale characters were suitable for combining brood years.

The following can be concluded from these scale studies:

1. The average error in determining the ages of 180 red salmon by three trained personnel was 13 percent per reader. This difference did not affect the accuracy of circuli counts and measurements of scale width.

2. A scale axis can be selected with an average deviation of plus or minus two degrees and a maximum expected deviation of plus or minus ten degrees. No bias is introduced by this amount of variation.

3. It is important to always use the same scale axis to measure and count scale characters. Deviations could cause error in determining the origin of fish taken at sea.

4. The body zone from which a scale is taken is important. Some scales taken from body area C below the lateral line are questionable for determining ages. Scales from body area A are acceptable for determining scale characters.

5. Sampling dates can be ignored as a source of variation for Bristol Bay rivers.

6. No difference was found between scales from male and female fish in measurements or circuli counts in the freshwater zone, or in the part of the scale reflecting the first year of sea life. Data for males and females can be combined for these scale characters.

7. The circulus count and scale width of the first ocean zone was found to be free of differences arising from variations in freshwater age and growth patterns.

8. Only the total freshwater scale length is free from variations connected with differing ocean ages.

9. Brood year differences occur for all scale characters, and brood years are a definite source of variation.

PINK SALMON STUDIES

by Roger E. Pearson

Three morphological characters were obtained from salmon collected in 1957 and used for a preliminary study to examine their utility in separating Asian from North American pink salmon in offshore samples. Results were reported in Amos *et al.* (1960). It was found that North American pink salmon from spawning areas south of Kodiak Island and Cook Inlet were distinguishable from pink salmon of the major Asian spawning areas. The characters could not separate pink salmon of the Alaska Peninsula, Aleutian Islands and northwestern Alaska from those of Kamchatka. Since it is probable that these North American fish are present in the high seas samples, additional research to obtain their separation was initiated. This research was directed toward two goals: the first was to examine a set of new scale characters to determine their suitability for use in the separation analysis of 1959 samples, the second was to classify correctly all 1959 North American inshore samples to their natal continent and identify the origins of the fish in the 1959 high seas samples.

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INTER-NATIONAL COOPERATION

EQUALANT

Thomas S. Austin

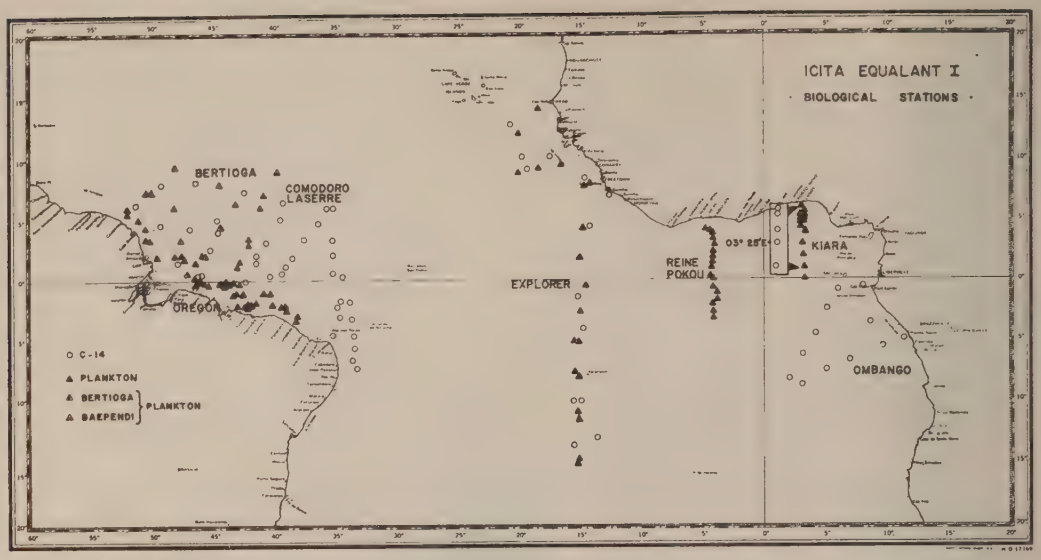
The International Cooperative Investigations of the Tropical Atlantic (ICITA), a multiple vessel oceanographic study of the Tropical Atlantic Ocean, were undertaken during 1963. These investigations, coordinated by UNESCO's Intergovernmental Oceanographic Commission (IOC), involved the participation of 13 vessels from seven nations (EQUALANT I, February-April, 1963) and 11 vessels from eight nations (EQUALANT II, August-September, 1963). Scientists from three additional nations, in addition to those operating research vessels during the investigations, also participated.

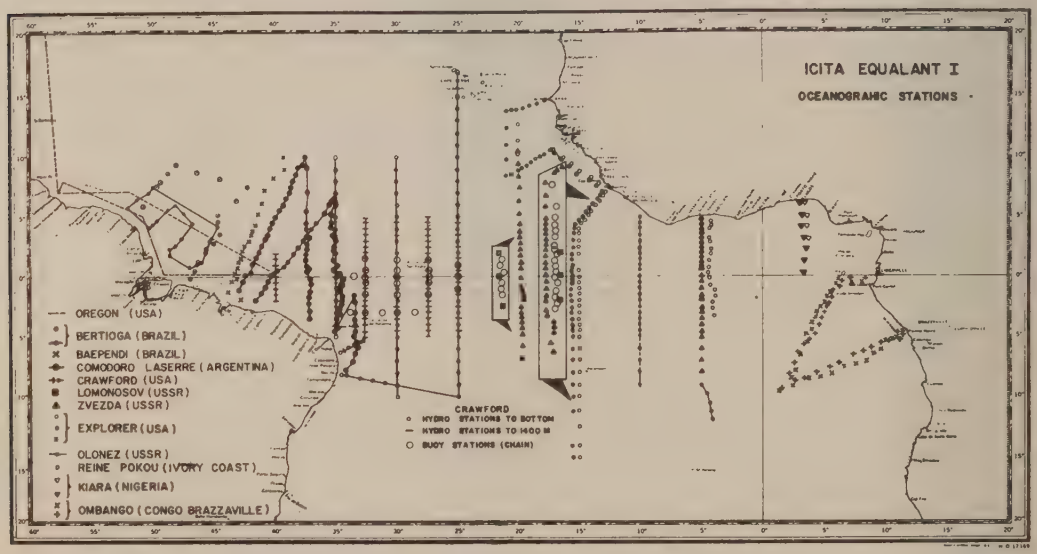
The ICITA evolved from a proposal by the Commission for Technical Cooperation in Africa (CCTA) to make coordinated investigations of West African waters from the mouth of the Congo River north to Dakar, Senegal. In early 1961, the Bureau of Commercial Fisheries proposed that the Bureau cooperate with CCTA by making a study of the oceanographic areas of the Gulf of Guinea. The interest of other oceanographic and fishery research organizations in this area and in adjacent areas of the Tropical Atlantic led to a meeting in February 1962 of representatives from various United States, Argentine, and Brazilian activities. A plan for a multiple vessel investigation of the Tropical Atlantic developed at that meeting and was subsequently presented to the UNESCO Intergrovernmental Oceanographic Commission for consideration as an international effort. In June 1962, representatives from 17 member nations met in Washington, D. C., to prepare the detailed plans for the ICITA. These plans were formally adopted by the Second Session of the IOC in September 1962.

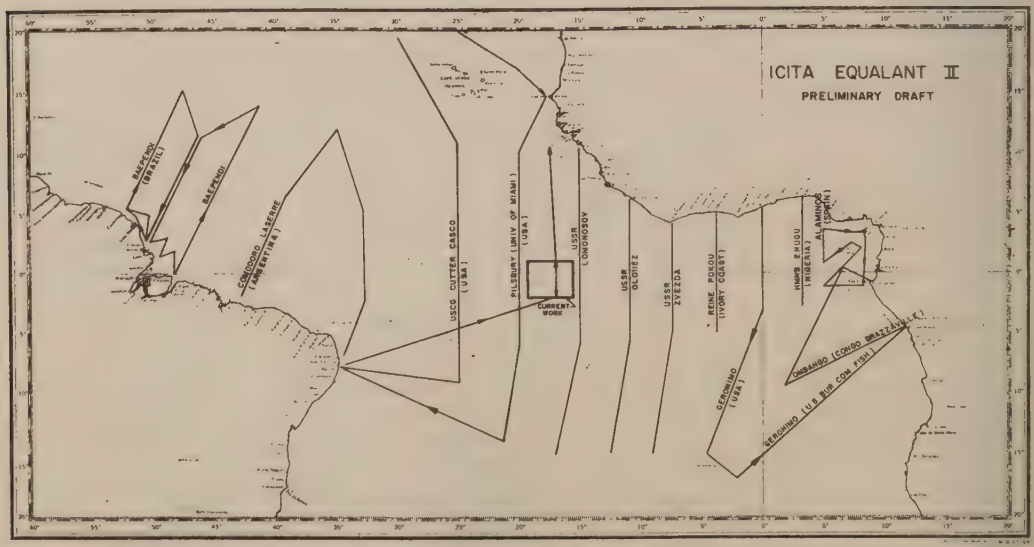
Oceanographers from many nations have been studying the waters of the Tropical Atlantic ocean for about 100 years. Some of the famous research vessels which have worked in this area are the *Challenger* (England, 1873 and 1876), *Blake* (USA, 1879), *Talisman* (France, 1882), *Gauss* (Germany, 1901), *Deutschland* (Germany, 1911), *Dana* (Denmark, 1921 and 1928), *Carnegie* (USA, 1928), *Meteor* (Germany, 1926 and 1938), *Albatross* (Sweden, 1938), *Atlantis* (USA, 1959), and the *Lomonosov* (USSR, 1960).

Although physical, chemical, biological, and fishery observations have been made and samples collected in the tropical Atlantic waters from over 50 research vessels, the total available data are insufficient to adequately describe the area. From 20°N to 20°S latitudes between the coast of South America and Africa is an area of over 7,000,000 square nautical miles, which is more than twice that of the continental United States. A total of approximately 2,200 oceanographic stations were made in this area between 1900-1960. The inadequacy of these data, especially for consideration of seasonal variations, is the month of June (all years together) well demonstrated by the fact that for there is an average of one station per 250,000 square nautical miles, and for February, one station per 18,000 square nautical miles.

So large is the task of collecting sufficient data to study the seasonal variations in tropical Atlantic waters, that


ICITA EQUALANT I
BIOLOGICAL STATIONS
BERTIOGA
COMODORO LASERRE
OREGON
EXPLORER
REINE POKOU
03° 25'E
KIARA
OMBANGO
C-14
PLANKTON
BERTIOGA
BAEPENDI
PLANKTON


ICITA EQUALANT I
OCEANOGRAPHIC STATIONS
OREGON (USA)
BERTIOGA (BRAZIL)
BAEPENDI (BRAZIL)
COMODORO LASERRE (ARGENTINA)
CRAWFORD (USA)
LOMONOSOV (USSR)
ZVEZDA (USSR)
EXPLORER (USA)
OLONEZ (USSR)
REINE POKOU (IVORY COAST)
KIARA (NIGERIA)
OMBANGO (CONGO BRAZZAVILLE)
CRAWFORD
HYDRO STATIONS TO BOTTOM
HYDRO STATIONS TO 1400 M
BUOY STATIONS (CHAIN)


ICITA EQUALANT II
PRELIMINARY DRAFT
BAEPENDI (BRAZIL)
BAEPENDI
COMODORO LASERRE (ARGENTINA)
USCG CUTTER CASCO (USA)
PILSBURY (UNIV OF MIAMI) (USA)
CURRENT WORK
USSR LOMONOSOV
USSR OLONEZ
USSR ZVEZDA
REINE POKOU (IVORY COAST)
HMS EHIOU (NIGERIA)
ALAMINOS (USA)
GERONIMO (USA)
OMBANGO (CONGO BRAZZAVILLE)
GERONIMO (U.S. BUR COM FISH)

ne nation could undertake this task
ne year, except by assigning all, or
ajor portion, of its presently avail-
qualified marine scientists and re-
ch vessels. International coopera-
such as the ICITA, with coordi-
d effort of vessels and scientists
several nations, is one means
reby oceanographic studies of large
s may be carried out on a quasi-
optic basis.

he positions of the oceanographic
ons made during the 1963 mid-
er investigations of the ICITA
UALANT I), are shown on Fig. 1;
e for the biological samples are
vn on Fig. 2. The cruise tracks
duled for participants during the
mer investigations (EQUALANT
are shown on Fig. 3.

hysical-chemical data at each station
the surface to 2,000 m (to the
om at 120-mile intervals), included
perature, salinity, oxygen, and inor-
is phosphate determinations. Bathy-
mograph lowerings were scheduled
0-mile intervals; surface meteorolo-
l data were recorded at the time of
BT lowering, as well as at six
rly intervals. The biological program
uded daily measurements of both
nary productivity, using the C-14
nique and of the microbiomass,
g a technique developed by Dr.
annes Krey, University of Kiel, Ger-
y. In addition, one oblique zoo-
kton tow to the top of the thermo-
ie was made at 2,200 hours daily.

Supported in part by a grant from the Atomic Energy Commission, standard equipment and supplies for the C-14 and zooplankton programs were furnished to each vessel by the Bureau of Commercial Fisheries; those for the microbiomass were furnished by Dr. Krey. Standard instructions for the biological programs were furnished to each vessel.

Samples for measurement of primary productivity were collected in nontoxic, six-liter, plastic bottles from five depths, from the surface (100% of incident radiation), and at depths of 70%, 50%, 10% and 1% of incident radiation. These samples, following inoculation with the C-14 isotope (one light and one dark bottle from each of the five depths) were incubated on deck in running sea water for a period of 24 hours. Filters, with light transmission characteristics for each of the chosen percentages of incident radiation, were laminated in the hinged plastic lids of the incubators. Following incubation, the samples were filtered through millipore filters. The filters, each in a separate glassine envelope, were airmailed to the International Coordinator.

The oblique, one-half hour zooplankton tows to the top of the thermocline, were made with one-meter nets, of which two were supplied to each participant. Flow meters provided with the nets were calibrated at the U. S. Navy's David Taylor Model Basin, Washington, D. C.

In conjunction with the primary productivity studies, samples for microbiomass determinations were collected from each of the five depths selected for measurement. Five liters of water were filtered in a low pressure filtration system; the filters were dried and forwarded to the Institut für Meerskunde, Kiel University.

In an effort to minimize variability in the biological data, all C-14 planchettes are being counted at the Bureau of Commercial Fisheries Radiobiological Laboratory, Beaufort, North Carolina, displacement volumes of the zooplankton samples determined at the BCF Biological Laboratory, Washington, D. C., and analyses of the microbiomass samples at Kiel University, Germany. Following displacement volume determinations, the zooplankton samples will be sorted into *circa* 35 faunistic categories by the Smithsonian Oceanographic Sorting Center, U. S. National Museum, Washington, D. C.

All data from the ICITA are being forwarded to World Data Center A for Oceanography, Washington, D. C. The National Oceanographic Data Center (NODC), Washington, D. C. will publish data reports, the first volume (EQUALANT I) being scheduled for publication in the late fall of 1963. The NODC has also prepared a proposal for preparation and publication of an ICITA Atlas of the analyzed results.

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79-87

Abundance of Postlarval Shrimp — One Index of Future Shrimping Success[1]

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Galveston, Texas

Abstract

The feasibility of forecasting offshore abundance of commercial-size shrimp from preseason counts of postlarvae as they enter passes to inshore nursery grounds is discussed. Indices derived from the results of 3 years' postlarvae sampling inside Galveston Entrance are correlated with corresponding measures of juvenile abundance on the nursery grounds and, in turn, with appropriate measures of adult abundance on offshore fishing grounds. Indices of juvenile and adult abundance are provided by commercial fishery statistics. The method employed to sample postlarvae is described.

INTRODUCTION

THE BROWN SHRIMP, *Penaeus aztecus*, spawns in the offshore waters of the Gulf of Mexico in all seasons, with the greatest activity taking place between late January and early April. The resulting larvae quickly transform to postlarvae which probably arrive at the barrier islands and passes, such as Galveston Entrance, from four to five weeks after spawning and hatching take place. Some six to eight weeks later the young shrimp reach a size which makes them legal for sport fishing bait and soon thereafter return to open Gulf waters where they are henceforth exploited by the commercial fleet.

A continuing survey of the movements of postlarval shrimp into the Galveston Bay system was begun in November of 1959. It was felt that if a reliable measure of postlarval abundance could be so obtained, it might serve as an index with which offshore shrimp production during the last half of the same year could be predicted. This survey has since provided semiweekly counts of all penaeid postlarvae entering Galveston Bay, although discussion here will be limited to those of the brown shrimp.

Description of Postlarval Survey

SAMPLING GEAR: Samples are collected semiweekly using a hand-drawn beam trawl fitted with a plankton net at the cod end (Renfro, In press). The net is 5 feet wide (along both cork and lead lines) by 2 1/3 feet long. The wings are made of nylon material having 50 holes per square centimeter. The body

[1] Contribution No. 172 Bureau of Commercial Fisheries Biological Laboratory, Galveston, Texas.

tapers to a canvas cylinder about 5 inches in diameter and 8 inches long. 12-inch, #1-mesh plankton net with a removable bucket is fitted over collar. The plankton net is secured by a snap and ring arrangement.

Around both collar and plankton net is fitted a 2¼-foot section of li canvas which acts as chafing gear. A 7-foot piece of 3/16-inch stainless st cable, onto which are threaded additional lead weights, serves as the n lead line. The ends of the cable are attached by means of swivels to the e of a 6-foot length of 11/16-inch stainless steel pipe which constitutes beam. To the cork line are threaded five 2¾-inch sponge floats. The cork l ends are tied directly to the beam, 8 inches from either end. A 15-foot len of nylon parachute cord serves as the bridle line. The effective opening the net unit is approximately 5.8 square feet.

Sampling Procedure: The sample is taken in the following manner. A 6-f stake (½-inch galvanized tubing) with 150 feet of nylon parachute c attached, is driven into the ground at the shoreline. The cord is payed out stretched taut parallel to the water line. Using the cord as a constant radi the operator pulls the net assembly along the bottom in a half circle. T method is duplicated each time so that standard tows are obtained. The de of tow varies from 0 to 4 feet depending on tidal conditions and roughn of the water. The effective length of each tow is about 470 feet, the volu of water sampled is 2,477 cubic feet, and the bottom area traversed is 1,1 square feet. These are average measurements and vary according to the cont of the shoreline. The postlarvae sample is immediately preserved in a 5 buffered solution of formalin in sea water. Together with the sample postlarvae, a water sample for salinity determination is obtained and following observations are made: air and water temperatures, current direct and velocity, tide conditions, turbidity, condition of sea and sky, force direction of wind, and the presence and abundance of fish in the immed vicinity.

At the laboratory penaeid postlarvae are removed from each sample, t identified and counted. Identification to species is made using the descrip characteristics noted by Pearson (1939) and Williams (1959).

It is believed that the important "spring run" of postlarvae consists aln entirely of brown shrimp and that chances of taking pink shrimp, *Pena duorarum*, postlarvae in Galveston Entrance between February and May very slight. Of 27,700 juvenile shrimp examined from Galveston Bay shrimp samples between January, 1960 and October, 1962, only 13 were ide fied as pink shrimp. This species was never found in bait samples secured l than mid-May. Two specimens obtained on May 19, 1961 had an ave weight of 8.4 grams whereas the mean weight for 84 juvenile brown shr in the same bait sample was 2.9 grams. It is assumed, on the basis of prelimi knowledge of the brown shrimp's growth pattern, that the latter specim had entered Galveston Bay as postlarvae in March and April. In contrast, quite unlikely that the much larger pink shrimp had passed through the s stage in the same period.

To supply anglers in the Galveston area during winter months, bait dea often transport shrimp from other areas in aerated tank trucks (Chin, 19 Most of those brought from the Matagorda Bay area are pink shrimp, som which could have escaped the live bait boxes and survived to be taken following spring. It is also reasonable to assume that fishermen having

s imp left after a fishing trip released them in the area, only to have them r aught when trawling for bait shrimp intensified in May.

Sampling Sites and Frequency: The first sampling station was established in t Bolivar Roads area near the south jetty on the east-end sand flats of Galveston Island (SF, Fig. 1). Semiweekly samples were taken at this site f m November, 1959 to May, 1961, and again from mid-August to September 1961. During the period September 9 to 12, 1961, flood waters from Hurricane Carla cut a channel approximately 200 feet wide and 14 feet deep through t sand flats adjacent to the jetty, making the station site inaccessible. Following the hurricane, a new monitoring station (BSF) was selected on Bolivar Peninsula in a cove off State Highway 87 opposite the abandoned lighthouse. This location was used from September 25 to November 21, 1961. When this section of beach was fenced off, a third station site was selected midway between the north jetty and the Fort Travis ruins on Bolivar Peninsula (BJSF-1).

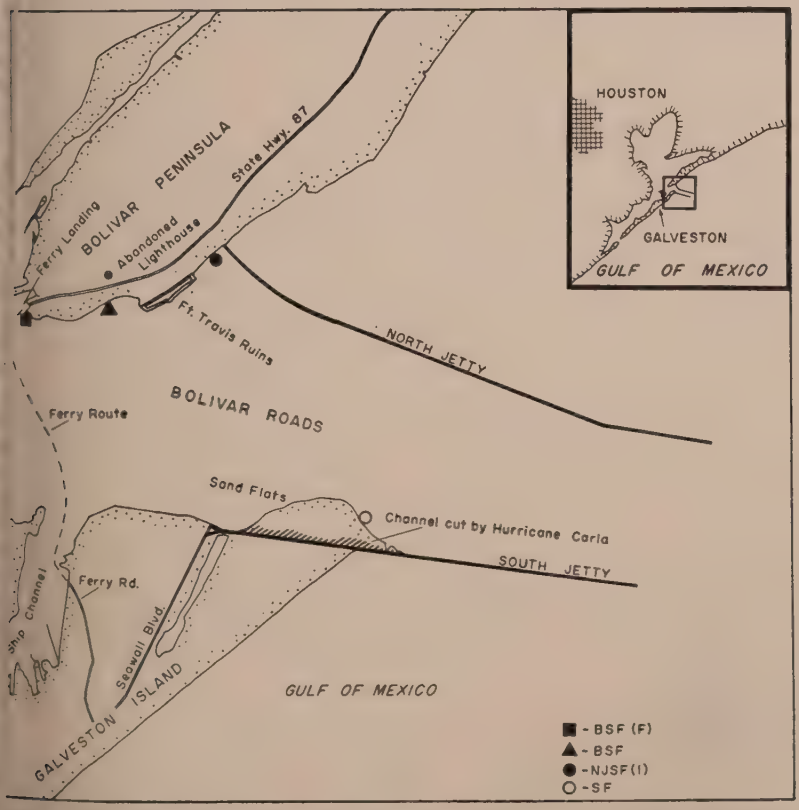

Fig. 1. Galveston Entrance showing location of stations at which postlarval shrimp were sampled.

TABLE 1

RESULTS OF SAMPLING FOR BROWN SHRIMP POSTLARVAE IN GALVESTON ENTRANCE, 1960-62.

Item	Year	MONTH Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Number of samples	1960	7	8	8	9	9	9	8	9	9	9	8	9
	1961	9	7	8	7	2	—	—	6	4	10	9	8
	1962	9	8	11	9	9	9	9	9	8	9	9	—
Total number of postlarvae	1960	19	13	4919	4989	34	379	509	838	10	4	6	7
	1961	0	6	183	246	940	—	—	97	694	268	76	43
	1962	241	1847	3495	2514	290	62	50	310	515	Counts not completed		
Range	1960	0-12	0-3	0-4710	0-3680	0-9	0-167	0-241	0-306	0-4	0-2	0-3	0-6
	1961	—	0-4	0-97	0-209	0-889	—	—	0-54	4-620	0-144	0-45	0-20
	1962	0-224	1-1220	0-1083	3-1682	0-250	0-32	0-14	0-153	0-351	—	—	—
Number per sample	1960	3	2	615	554	4	42	64	93	1	1	1	1
	1961	0	1	23	35	470	—	—	16	174	27	8	5
	1962	27	231	318	279	32	7	6	34	64	—	—	—

Twice-weekly sampling has since been carried on at this site with the ception that in early June, after vast quantities of "seaweed" (*Sargassum tans* and *S. fluitans*) built up in the area, an alternate station (BSF-F) was tablished at the ferry landing. Although the cove in which this station site located affords room for only half the normal towing space required, it was otected to some extent from the southeasterly winds which piled seaweed onto e beach at the regular station site. Between June 4 and July 12, 1962, nine ws were made at this location. The presence of seaweed began to hamper mpling operations as early as April 23 and continued to impede them rough May, June, and July. As of this writing (November, 1962), samples e still congested with decomposing weed which continues to litter the bottom the sampling area.

Over the 3-year period, all tows were made during daylight hours, alternating om morning to afternoon so as to sample during both flooding and ebbing des. Fig. 2 shows the movement of brown shrimp postlarvae through alveston Entrance for the 3-year study period. From 7 to 9 tows were rdinarily made each month. Wide variation in the numbers of postlarvae ccurring in each sample indicated that, while immigration may have been ntinuous during seasons of peak abundance, its intensity fluctuated broadly Table 1).

ndices of Abundance

OMMERCIAL FISHING OPERATIONS: The number of commercial bait trawlers perating in the Galveston Bay area fluctuates annually between 85 and 125, ne number of dealers between 100 and 145. Bait shrimp are caught with small hrimp trawls ranging from 10 feet to a maximum width of 25 feet along the ork line. Mesh sizes vary from 1½- to 1¾-inch stretched measure. These ets are towed principally by small trawlers ranging up to 35 feet in length, ut a few dealers are supplied from catches made with outboard-powered kiffs. Although bait shrimp may be legally taken from the bay throughout the ear, most production occurs from May to October.

OLLECTION OF STATISTICS: Approximately 50 bait dealers are interviewed each veek by means of a continuing sample survey. Production and effort statistics re obtained along with information on area(s) fished, number of fishing trips, nd time spent trawling. Since January, 1959, monthly estimates of total production and effort have been made utilizing these data. Samples of live or fresh-rozen shrimp, which provide material for determining growth as well as atch size and species composition are obtained weekly from each section f the Galveston Bay system.

DERIVATION OF INDICES: The monthly index of brown shrimp postlarval abundance was obtained by dividing the total number of postlarvae collected during a given month by the number of tows made in the same period. The resulting number of postlarvae per tow, or postlarval index, is plotted serially in Fig. 3.

In order to obtain a juvenile index, total monthly brown shrimp bait production (pounds) was divided by total effort expended (hours). The resulting catch per unit of effort (pounds per hour's fishing) was used as a monthly index to juvenile brown shrimp abundance on the nursery grounds.

An index of adult brown shrimp abundance, expressed in terms of the average catch of commercial-size brown shrimp per 24 hours' trawling off the upper Texas coast (Fig. 3) was obtained by dividing the monthly catch of

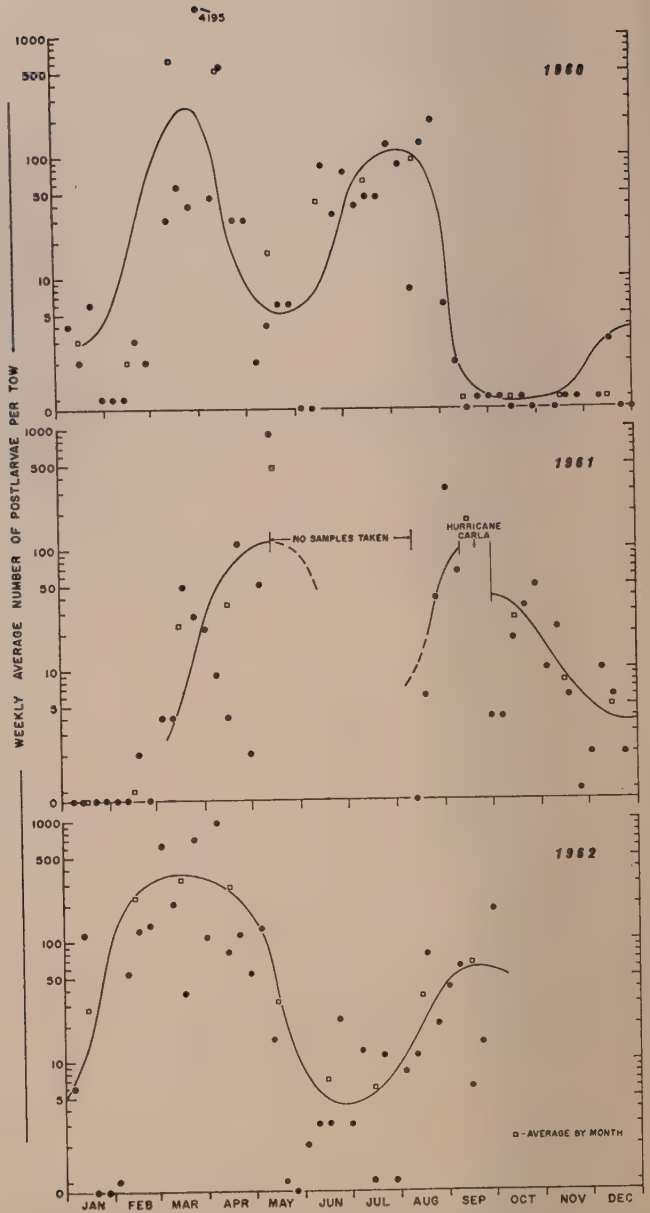

FIG. 2. Relative density of brown shrimp postlarvae occurring in Galveston Entrance, 1960-62.

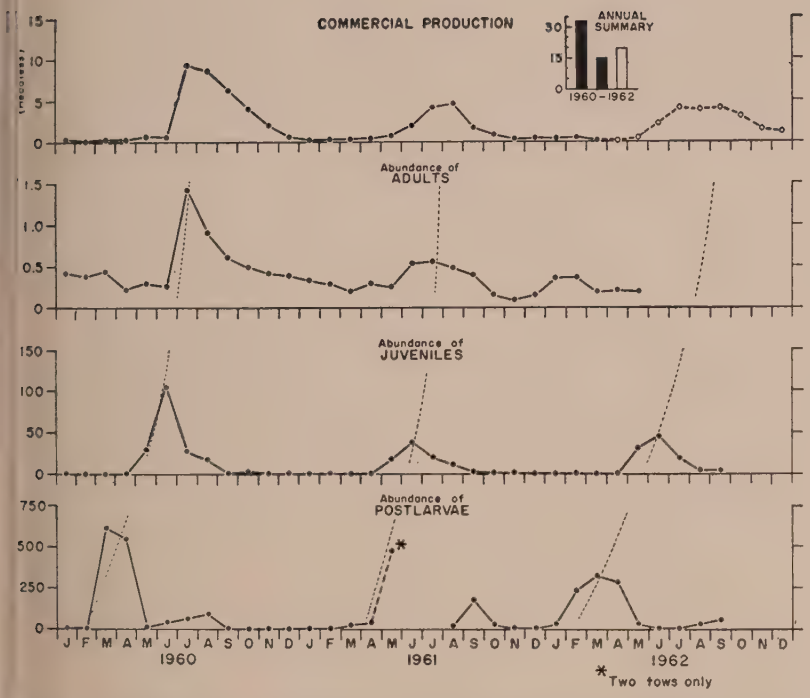
COMMERCIAL PRODUCTION
ANNUAL SUMMARY
1960-1962
Abundance of ADULTS
Abundance of JUVENILES
Abundance of POSTLARVAE
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1960
1961
1962
*Two tows only

FIG. 3. Correlation of abundance indices for brown shrimp postlarvae, juveniles, and adults with subsequent offshore production, Galveston and upper Texas coast, 1960-62. (Unshaded portion of production graph indicate preliminary estimates for 1962.)

brown shrimp by the corresponding number of days fishing time expended. Production and effort statistics used to derive this index were obtained from tables entitled *Gulf Coast Shrimp Catch by Area, Depth, Variety and Size* published monthly by the Bureau of Commercial Fisheries.

Consolidation of these indices for comparative purposes is attempted in Table 2. Here, the postlarval index for each of the three years involved was obtained by dividing the total number of brown shrimp postlarvae taken during months of greatest postlarval movement (February, March, April and May), by the total number of samples taken in the same period.

The juvenile index was obtained by combining catch values for the three months of peak brown shrimp bait production on the nursery grounds (May, June, and July), and dividing this figure by the combined effort expended by bait fishermen during the same period.

The adult index (Table 2) was developed by considering only commercially acceptable brown shrimp of a size that could conceivably have been young-of-the-year, *i.e.*, February-May postlarvae and May-July juveniles. Thus the catch of small shrimp (41 headless-count and smaller) taken from statistical

TABLE 2

COMBINED INDICES OF BROWN SHRIMP ABUNDANCE AT EACH OF THREE LIFE HISTORY STAGES IN THE GALVESTON AREA AND OFF THE UPPER TEXAS COAST, 1960-62

YEAR	POSTLARVAE February-May (number/std. tow)	JUVENILES May-July (pounds/hour)	ADULTS June-September (pounds/24 hours)*
1960	297	54	260
1961	134	25	116
1962	215	32	Not yet available

*Includes small shrimp only (41 headless-count and smaller).

subarea 18 off Galveston (Kutkuhn, 1962) during June, July, August, an September, divided by the corresponding number of days fished, yielded th required index.

DISCUSSION OF RESULTS, 1960-62

Primary peaks of brown shrimp postlarvae occurred annually between mi February and mid-May, secondary peaks between late July and mid-Septemb (Figs. 2 and 3). Maximum movement of postlarvae in 1960 occurred durin March and April. In 1961, fewer postlarvae were taken and the greatest mov ment occurred in May. In 1962, postlarvae began to appear in large quantiti in February, and continued to enter the nursery area in comparable numbe during March and April.

In 1960, a high postlarval index in March and April was succeeded in Ma and June by a high juvenile index and record high bait shrimp productio (Fig. 3). Both indices forecast a great abundance of shrimp offshore in la summer. As it turned out, 1960 proved to be a record year for brown shrim production in western Gulf waters.

In 1961, the postlarval index dropped considerably compared with that 1960. A corresponding drop in bait shrimp production was also observe Commercial brown shrimp production in 1961 amounted to only abo one-half that of 1960. Parenthetically, it should be noted that only two po larvae samples were taken in May of 1961 (May 1st and 8th), each containi an average of 470 individuals. Unfortunately, sampling was discontinued this time and not resumed until mid-August, leaving the question unanswer as to whether counts from these two samples truly indicated the magnitude postlarval immigration during May. In any event, the postlarval maximum May, as suggested by the two samples, was not reflected in corresponding pl of juvenile abundance (Fig. 3).

In 1962, the postlarval index exceeded that of 1961, but fell somewhat sh of the 1960 index (Fig. 3). The juvenile index also showed an increase ov that for 1961. Although offshore production figures are not yet available f 1962, the supply as reflected by landings and amounts of discards shou measurably exceed that of 1961. Production, however, will probably r approach the record-high level of 1960.

Offshore abundance of adult shrimp was not accurately mirrored preliminary production figures for the months of June, July, and August

62. Abnormally large numbers of small brown shrimp, according to reports fishermen, were discarded at sea off the Texas and Louisiana coasts during is period. Over a 10-day period in August, 1962, observations aboard a mmercial trawler operating off Aransas Pass, Texas, revealed that approxiately 26 percent by weight (30 percent by number) of its shrimp catch was ing discarded because it failed to meet the minimum legal size. Texas law rbids the commercial fleet to land shrimp of 50 headless-count size or naller. If we assume that shrimp at this life history stage grow in length out 15 mm per month, the discard rate a month earlier (July) would have en about 50 percent by weight (60-70 percent by number).

SUMMARY

To determine their possible use in predicting catch potential for the ommercially important brown shrimp, indices derived from the results of 3 ears' postlarvae sampling inside Galveston Entrance are correlated with rresponding measures of juvenile abundance on the nursery grounds and, in rn, with appropriate measures of adult abundance on offshore fishing grounds. lthough further work is necessary in order to establish its reliability, it is pparent that the postlarval index forecasts quite well the relative magnitude f subsequent juvenile abundance in estuarine areas, as well as the ultimate uantity of commercial-size shrimp available offshore.

LITERATURE CITED

HIN, EDWARD

1960. The bait shrimp fishery of Galveston Bay, Texas. Trans. Am. Fish. Soc., *89* (2): 135-141.

UTKUHN, JOSEPH H.

1962. Recent trends in white shrimp stocks of the northern Gulf. Proc. Gulf and Carib. Fish. Inst., 14th Annual Session (1961), p. 3-16.

EARSON, JOHN C.

1939. The early life histories of some American Penaeidae, chiefly the commercial shrimp, *Penaeus setiferus* (Linn.). Bull. U.S. Bur. Fish. *49* (30): 1-73.

RENFRO, WILLIAM C.

1962. Small beam net for sampling postlarval shrimp. *In:* Galveston Biological Laboratory—Fishery research for the year ending June 30, 1962. U.S. Fish and Wildlife Service. Circular (In press).

WILLIAMS, AUSTIN B.

1959. Spotted and brown shrimp postlarvae *(Penaeus)* in North Carolina. Bull. Mar. Sci. Gulf and Caribbean. *9* (3): 281-290.

Limnological Survey of Lake Erie 1959 and 1960.

eat Lakes Fishery Commission

INICAL REPORT No. 6
mber, 1963

The Great Lakes Fishery Commission was established by the Convention on Great Lakes Fisheries, between Canada and the United States, ratified on October 11, 1955. It was organized in April, 1956 and assumed its duties as set forth in the Convention on July 1, 1956. The Commission has two major responsibilities: the first, to develop co-ordinated programs of research in the Great Lakes and, on the basis of the findings, recommend measures which will permit the maximum sustained productivity of stocks of fish of common concern; the second, to formulate and implement a program to eradicate or minimize sea lamprey populations in the Great Lakes. The Commission is also required to publish or authorize the publication of scientific or other information obtained in the performance of its duties.

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LIMNOLOGICAL SURVEY OF LAKE ERIE

1959 AND 1960

by

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U.S. Fish and Wildlife Service
Ann Arbor, Michigan

GREAT LAKES FISHERY COMMISSION
NATURAL RESOURCES BUILDING
THE UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN

1963

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LIMNOLOGICAL SURVEY OF LAKE ERIE

1959 AND 1960

Alfred M. Beeton

ABSTRACT

Federal, provincial, state, and university organizations participated in cooperative limnological surveys of Lake Erie in September 1959 and August 1960 to determine the extent and severity of the low dissolved-oxygen content of the hypolimnetic waters. Observations were restricted to the central basin in 1959, but were lake-wide in 1960. Approximately 70 percent of the bottom waters of the central basin had a serious oxygen deficiency during both years. Data were obtained also on the distribution of temperature, transparency, specific conductance, pH, and phenolphthalein and total alkalinity. The distributions of the chemical values are discussed in terms of their relationships to each other, and to thermal stratification, river outflow, lake morphometry, and lake currents.

Introduction

Fishery biologists studying Lake Erie have become increasingly concerned over the accumulating evidence of accelerated eutrophication of this highly productive lake. The benthos has changed substantially in the western basin, and increases have taken place in mean annual water temperatures, in coliform bacteria, and in the concentrations of the major chemical constituents of the water. Changes in the fish population, such as the collapse of the cisco (*Coregonus artedi*) fishery *ca.* 1925 (Van Oosten 1930), the decline in the abundance of sauger (*Stizostedion canadense*), the recent near-disappearance of the blue pike (*Stizostedion vitreum glaucum*), and the long-term upward trend of the walleye (*Stizostedion vitreum vitreum*) from the early 1930's to the middle 1950's, are well documented in the published statistics or in special reports. Increases in gizzard shad (*Dorosoma cepedianum*), alewife (*Alosa pseudoharengus*), and smelt (*Osmerus mordax*) have been large, but quantitative information on abundance is limited because these species have not been exploited commercially, except for the smelt, within recent years (Beeton 1960).

The various agencies working on the lake increased their limnological sampling as a consequence of their concern over environmental conditions, and in August 1959 the Ohio Division of Wildlife found very low dissolved-oxygen concentrations near the bottom at several stations in central Lake Erie. Several other agencies were informed of this condition and a cooperative synoptic survey was organized to obtain information on the extent of the area affected. The results of this survey brought out the need for more detailed information; a lake-wide survey was made in August 1960.

Low concentrations of dissolved oxygen in central Lake Erie have been reported previously. The severity of oxygen depletion may, however, be greater at present than in the past. A larger area probably is involved and the period during which low concentrations occur may be longer now than in the past. A low of 0.8 ppm of dissolved oxygen was observed off Marblehead in August 1930 (Wright 1955) and concentrations of 4.4 and 4.8 ppm were found in mid-August during the 1929 survey of the central basin (Fish 1960). The Fisheries Research Laboratory, University of Western Ontario, reported low dissolved-oxygen concentrations of 3.1, 2.4, 3.8, and 2.1 ppm in 1948, 1949, 1950, and 1951 (Powers *et al.* 1960). The Bureau of Commercial Fisheries found dissolved-oxygen concentrations ranging from 2.8 to 1.0 ppm in July and August 1958. These scattered observations provide little information on the extent both in time and area of these low concentrations and offer a poor basis for comparison with earlier findings (Carr 1962). Consequently, the recent occurrences of water with low dissolved-oxygen content may not be indicative of a great change in the central basin. On the other hand, the average percentage saturation of dissolved oxygen, over comparable periods, was lower in 1958, 63.3 percent, than in 1929, 83.3 percent (Beeton 1960).

Dissolved oxygen is usually around 80-percent saturation in the bottom waters of the western basin, except during periods of prolonged calm and accompanying thermal stratification such as occurred in 1953 (Britt 1955). The western basin is shallow enough to permit mixing to the bottom throughout most of the year. The average percentage saturation for bottom waters in 1928-30 ranged from about 83 to 91 and was 80 in 1958 (Beeton 1960).

Only a few observations have been made of the dissolved-oxygen content of the deeper waters of the eastern basin. The available data, however, indicate that the percentage saturation in the bottom waters averages around 60 to 70, although much lower saturations may be found during the same period in the shallower central basin.

The Ohio Division of Wildlife, Ontario Department of Lands and Forests, and the U.S. Bureau of Commercial Fisheries cooperated in the 1959 survey of the island area of the western basin and the western two-thirds of the central basin. Fifty stations were established during the survey on September 4-5 (Figure 1) . These stations were visited as follows:

George L.	U.S. Bureau of Commercial Fisheries	10-12, 14, 16-21, 23
Keenosay	Ontario Department of Lands and Forests	24, 26-29, 31,32, 41,42, 44-48
SP2	Ohio Division of Wildlife	49-57, 66-73, 49A, 49B, 67A
SP1	Ohio Division of Wildlife	59, 61-65, 58A-65A[1]

The Great Lakes Institute of the University of Toronto, Ohio State University, Ohio Division of Shore Erosion, and Pennsylvania Fish Commission joined the 3 original agencies in the lake-wide synoptic survey of August 30-31, 1960. Most of the 1959 stations were revisited and sampling was carried out at 168 stations (Figure 2). The 78 stations established by the *Porte Dauphine* are listed separately, since sampling was conducted underway and it was convenient to tabulate these observations in a special table. Provision was made for sampling for 30 hours at Stations 35, 37, 69, and 85. The *Alvera* and *SE1* completed their sampling at Stations 35 and 37, but 2 small boats from the Great Lakes Institute could not occupy Stations 69 and 85 because of a heavy swell in the eastern end of the lake.

Vessels from 7 agencies sampled at the following stations:

Porte Dauphine	Great Lakes Institute	1D-78D[2]
George L.	Bureau of Commercial Fisheries (Biological Research)	1-9, 1A, 2A
BioLab	Ohio State University	10-23
Keenosay	Ontario Department of Lands and Forests	24-34, 36, 38-40

[1] Engine trouble aboard the *SP1* delayed sampling at 7 stations until September 7.

[2] Stations occupied by the *Porte Dauphine* are not shown in Figure 2 but their positions are given in Table 7.

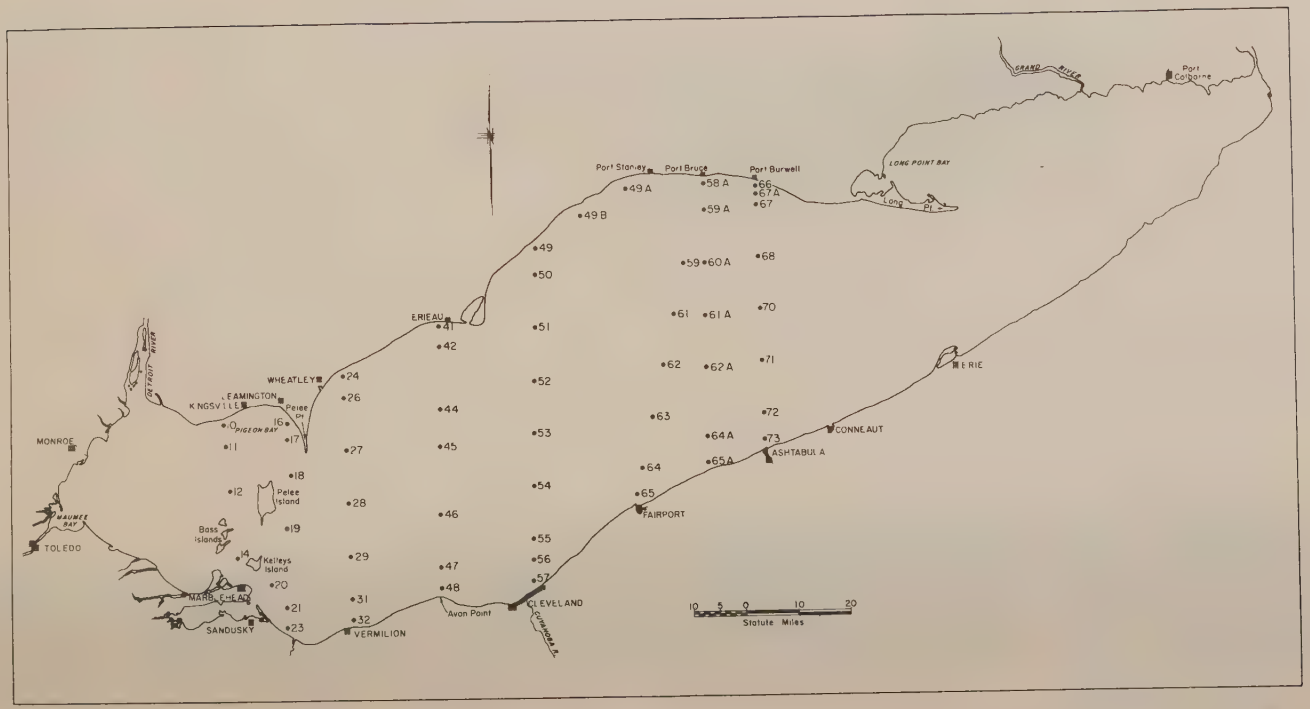

Figure 1. 1959 Stations

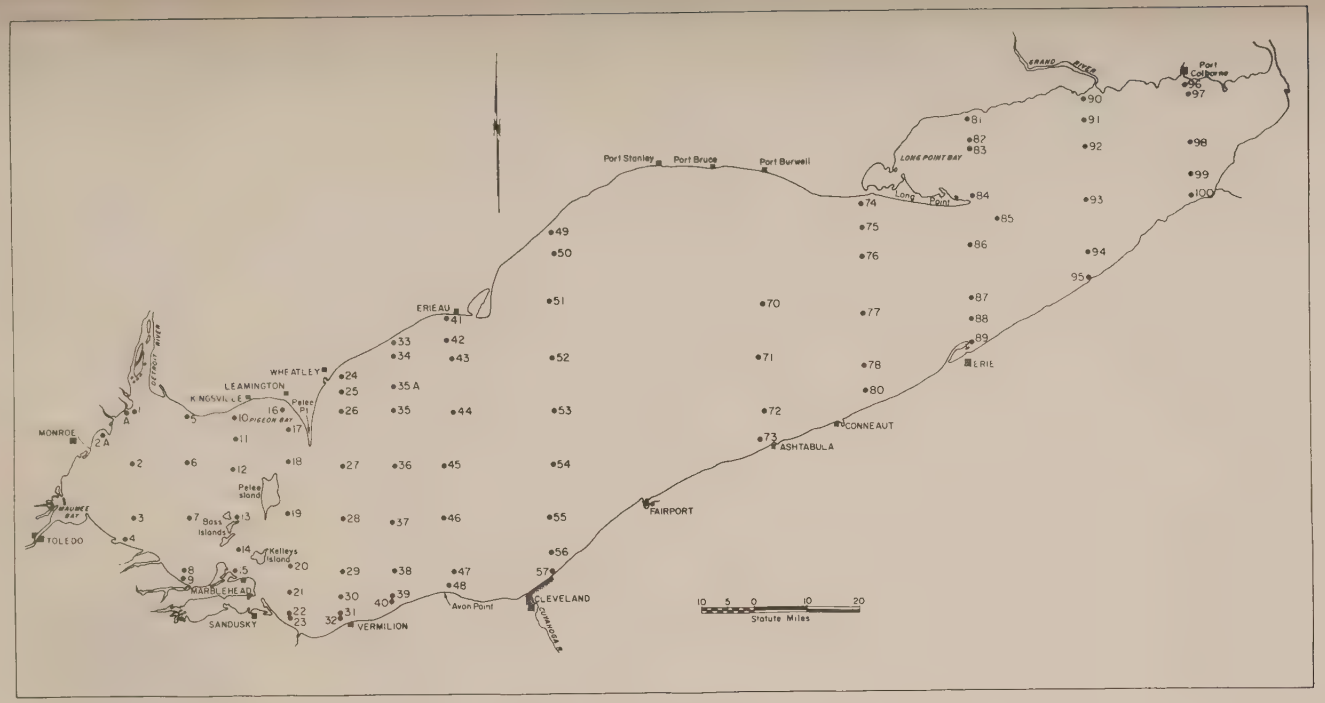

Figure 2. 1960 Stations

Alvera	Ontario Department of Lands and Forests	35
SE1	Ohio Division of Shore Erosion	37
SP3	Ohio Division of Wildlife	41-57
SP4	Ohio Division of Wildlife	70-73[3]
Perca	Pennsylvania Fish Commission	74-89
Active	Bureau of Commercial Fisheries (Exploratory Fishing)	90-100, 96A

Acknowledgments

The following investigators were primarily responsible for organizing and carrying out the 1959 and 1960 surveys; those designated by an asterisk participated only in the 1960 survey:

Merryll Bailey, Ohio Division of Wildlife
*Alfred M. Beeton, Bureau of Commercial Fisheries (Biological Research)
*N. Wilson Britt, Ohio State University
*Ira A. Carr, Bureau of Commercial Fisheries (Exploratory Fishing)
*R. E. Deane, Great Lakes Institute, University of Toronto
Robert Ferguson, Ontario Department of Lands and Forests
John Parsons, Bureau of Commercial Fisheries (Biological Research)
Charles Selden, Ohio Division of Wildlife
Nelson Thomas, Ohio Division of Wildlife
Harry Van Meter, Bureau of Commercial Fisheries (Biological Research)
*James Verber, Ohio Division of Shore Erosion

Field Procedures and Methods

Transects were laid out so the vessels traveled approximately due south or north. Two transects were assigned to each vessel. A vessel crossed the lake on one transect the first day of the survey and returned on the other transect the second day.

[3] Only 4 of the 17 stations designated for sampling by the *SP4* were visited because of engine trouble.

Water samples were taken immediately above and below the thermocline and near the bottom in 1959. If the water was homothermous, samples were taken near the surface and near the bottom. Determinations were made for dissolved oxygen by means of the unmodified Winkler method. Temperatures and transparency were determined aboard each vessel with bathythermographs and Secchi discs.

Water samples were taken at the surface, immediately below the thermocline, and near the bottom in 1960 by all vessels except the *Porte Dauphine* which took only surface samples. Bathythermographs were lowered from all vessels except aboard the *Perca* where a Foxboro resistance thermometer was used. Transparency was measured with Secchi discs on all vessels except the *Porte Dauphine*. Only limited meteorological observations, such as cloudiness, visibility, and wind direction and approximate velocity, were made aboard most of the vessels. Complete records were kept aboard the *Porte Dauphine* of the above conditions as well as barometric pressure, sea state, and wet- and dry-bulb temperatures. The dissolved-oxygen content of the water samples was determined on board all vessels by the sodium azide modification of the Winkler method (Am. Publ. Health Assoc. 1955). Percentage saturation of dissolved oxygen was determined from a nomograph prepared by Mortimer (1956). Phenolphthalein and total alkalinities (methyl orange) were determined aboard the *SE1, Perca, BioLab, SP3, SP4,* and *George L.* Some water samples were preserved with 2 to 5 percent formalin for plankton; others were left unpreserved for determination of specific conductance. Resistance measurements were made in the Ann Arbor Biological Laboratory of the Bureau of Commercial Fisheries with an Industrial Instruments Type RC-1613-1 conductivity bridge. Resistance was converted to specific conductance in μmhos/cm^3 at 18°C.

A few drift bottles (84) were released, but the small number recovered and the length of time before recovery made these data of little value; they have not been included in this report. Of the 31 bottles recovered, 5 to 61 days after release, only 2 were recovered within 2 weeks of release.

Some of the data as originally submitted by the agencies participating in the 1960 synoptic surveys were incomplete or had certain obvious inaccuracies. A subcommittee composed of A.M. Beeton, Bureau of Commercial Fisheries; N. Wilson Britt, Ohio State University; and Nelson Thomas, Ohio Division of Wildlife, was appointed by the Lake Erie Fish Management Committee to review procedures and results critically. Information on equipment used, records of accuracy of instruments,

and standardization of the sodium thiosulfate were obtained, and appropriate corrections were made in the data included in this report. Certain data collected were obviously incorrect and have not been included.

Survey of 1959

Meteorological observations. —The following information was obtained from the U.S. Weather Bureau records for Cleveland, Ohio, since extensive meteorological observations were not made aboard the vessels participating in the survey. Winds averaging about 7 to 9 mph were out of the south-southeast, September 4-6. The sky was clear during most of this time. The relative humidity averaged around 65 percent in the morning, decreased to about 25 to 30 percent at noon, and increased again in late afternoon. During the 7 days prior to the survey the winds averaged 5 to 10 mph; consequently, only slight mixing of the waters could have occurred.

Transparency.—The transparency, as measured by Secchi disc, ranged from 4 to 6 feet around the islands in the western basin (Tables 1 and 2). The maximum disc depth in this area was 9 feet just east of Pelee Island. The range in transparency was much greater in the central basin where disc depths ranged from 4 to 33 feet. In general the lower values of 4 to 15 feet occurred in shoal areas near shore, although isolated masses of low-transparency water were found in the open lake. Water with high transparency, 20 to 33 feet, lay in an extensive area of the open lake between Avon Point and Ashtabula. The transparency decreased in the western part of the central basin and toward the north and south shores. A few Secchi-disc measurements of from 17 to 19 feet were made north of Ashtabula in the eastern part of the central basin.

Surface temperatures.—The surface temperatures averaged about 2° F. higher in the west end than in the central basin. Temperatures ranged from 77° to 81° F. in the island area and from 74° to 80° F. in the central basin (Tables 1 and 2).

Two cooler masses of surface water (74° to 76° F.) extended from the north shore of the central basin—a small one immediately east of Pelee Point and a larger mass, about 25 miles wide, from the vicinity of Port Stanley almost to Fairport. Warmer surface waters (78° to 80° F.) occurred along the southern shore between Marblehead and Ashtabula.

Subsurface temperatures.—In general the subsurface temperatures in the west end were the same as the surface temperatures,

Table 1.—Physical and chemical data for Lake Erie, September 4, 1958

[Bottom refers to immediately above the bottom.]

Station Number	Latitude	Longitude	Depth at station (feet)	Thermocline depth (feet)	Temperature (° F.)		Dissolved oxygen[1] (ppm)			Secchi-disc depth (feet)
					Surface	Bottom	Above thermocline	Below thermocline	Bottom	
23	41°25'40"	82°34'30"	26	None	77	77	7.3	7.0	8.1	4.0
21	41 29 00	82 34 30	39	34[2]	77	70	7.2	6.9	0.0	12.0
19	41 41 50	82 34 30	41	36[2]	78	72	7.6	6.8	7.3	9.0
18	41 50 40	82 34 30	30	None	77	77	8.4	7.1	6.7	6.0
17	41 56 20	82 34 30	38	34[2]	78	68	7.0	6.8	7.0	6.0
16	41 59 00	82 34 30	30	None	78	77	8.1	7.0	7.1	4.0
10	41 58 40	82 48 50	25	None	78	75	6.9	4.7	2.4	6.0
11	41 55 20	82 48 20	35	None	79	78	8.6	...	6.7	4.5
12	41 48 00	82 47 20	31	None	79	78	8.9	...	7.3	6.0
14	41 36 50	82 45 30	31	None	80	78	9.3	...	6.4	4.5
20	41 32 40	82 37 50	39	34[2]	81	71	9.7	...	0.5	7.5
24	42 06 50	82 22 30	30	20-22	74.5	62.0	6.7	1.8	2.0	6.5
26	42 03 20	82 22 20	48	20-22	76.0	53.0	7.8	3.2	1.3	6.5
27	41 54 40	82 21 40	55	25-30	74.9	50.0	7.4	...	...	10.0
28	41 46 10	82 21 00	52	40-41	76.0	55.0	7.3	0.4	0.9	8.0
29	41 37 20	82 20 40	48	38-42	77.0	62.0	7.7	8.0	0.9	14.5
31	41 30 30	82 20 10	44	40-43	78.0	64.8	...	7.7	0.1	16.5
32	41 27 00	82 20 00	37	...	78.5	69.0	7.7	...	7.6	14.5
65	41 47 20	81 16 50	40	None	77.0	74.0	7.1	6.9	6.7	...
64	41 51 30	81 15 20	68	56-60	76.0	53.0	7.2	3.3	1.0	20.0
63	42 00 00	81 12 40	80	65-70	76.0	52.5	7.0	7.0	1.0	24.0
62	42 08 20	81 10 20	85	60-65	76.0	55.0	7.1	3.1	2.5	20.0
61	42 16 40	81 07 40	83	55-60	76.0	54.0	7.5	5.4	2.8	19.0
59	42 25 20	81 05 20	78	54-56	76.0	57.0	7.4	2.5	1.8	...
73	41 56 00	80 48 00	40	None	78.0	78.0	6.6	...	6.8	8.0
72	42 00 20	80 48 00	63	50[3]	78.0	52.0	6.9	6.9	4.6	19.0
71	42 09 00	80 48 20	72	50[3]	77.0	50.0	7.1	6.4	6.3	19.0
70	42 17 30	80 48 30	69	52[3]	77.0	51.5	6.8	6.3	5.9	17.0
68	42 26 00	80 48 40	68	48[3]	77.0	53.0	6.9	6.9	6.8	16.0
67	42 34 30	80 49 00	60	45[3]	75.0	57.0	6.9	5.2	4.6	15.0
67A	42 36 20	80 49 00	57	45[3]	76.0	58.0	7.2	6.3	6.2	16.0
66	42 37 40	80 49 00	40	None	77.0	71.0	6.9	7.0	6.2	6.0

[1] In the absence of a thermocline samples were taken near the surface and midway between the surface and bottom.

[2] Upper limits of thermocline.

[3] Lower limits of thermocline.

Table 2.—Physical and chemical data for Lake Erie, September 5, 1959

[Bottom refers to immediately above the bottom.]

Station Number	Latitude	Longitude	Depth at station (feet)	Thermocline depth (feet)	Temperature (° F.)		Dissolved oxygen[1] (ppm)			Secchi-disc depth (feet)
					Surface	Bottom	Above thermocline	Below thermocline	Bottom	
48	41°32'20"	82°00'20"	48	35-40	77.5	61.0	7.7	0.6	0.0	...
47	41 35 30	82 00 20	56	50-52	77.5	61.0	7.8	7.8	...	19.5
46	41 44 20	82 00 20	69	60-62	77.5	56.3	7.7	1.0	1.3	26.0
45	41 55 20	82 00 30	72	60-63	77.2	55.2	7.8	2.3	1.2	33.0
44	42 01 30	82 00 40	71	57-60	77.1	53.8	7.8	7.0	1.6	19.5
42	42 11 40	82 00 40	51	40-43	76.2	55.8	7.4	1.6	1.1	23.0
41	42 15 00	82 00 40	35	...	76.0	63.0	7.1	2.7	2.6	11.5
58A	42 38 20	81 00 40	39	None	75.0	75.0	7.2	...	6.9	6.0
59A	42 33 50	81 00 40	55	40-48	74.0	57.0	7.1	5.0	2.8	12.0
60A	42 25 20	81 00 40	62	50-56	77.0	56.0	7.1	3.6	3.7	13.0
61A	42 16 30	81 00 40	70	40-45	76.0	53.0	7.2	3.6	4.0	12.0
62A	42 08 00	81 00 40	72	45-50	76.0	51.0	7.3	5.3	5.3	13.0
64A	41 56 40	81 00 40	64	48-55	79.5	52.0	7.2	4.3	4.2	21.0
65A	41 52 20	81 00 40	26	None	80.0	75.0	7.1	6.9	6.9	13.0
49A	42 37 20	81 18 50	40	10-25	76.0	61.0	5.6	2.5	2.3	8.0
49B	42 33 00	81 28 30	47	25-35	76.0	61.0	7.5	1.0	0.7	13.0
49	42 27 40	81 38 40	31	15-25	78.0	65.0	7.8	3.7	2.1	13.0
50	42 23 30	81 38 40	59	35-45	75.0	54.0	7.4	2.1	2.2	13.0
51	42 14 40	81 38 50	75	15-45	77.0	52.0	7.8	2.0	1.7	8.0
52	42 06 00	81 39 00	79	53-79	78.0	55.0	7.1	1.7	2.2	24.0
53	41 57 30	81 39 20	79	55-70	76.0	52.0	7.3	1.9	1.5	10.0
54	41 48 40	81 39 30	78	58-68	78.0	55.0	7.6	2.0	1.7	20.0
55	41 40 10	81 39 40	67	57-59	78.0	57.0	7.3	7.3	0.6	20.0
56	41 36 40	81 39 40	55	42-45	78.0	61.0	7.7	1.2	0.5	13.0
57	41 33 20	81 39 40	40	None	79.0	76.5	8.4	...	5.1	10.0

[1] In the absence of a thermocline samples were taken near the surface and midway between the surface and bottom.

since the water was homothermous at most of the stations. Thermal stratification was found at Station 17, however, just west of Pelee Point.

Temperatures were low in the deeper water of the central basin, although the coldest waters did not occur at maximum depth. The lowest temperatures (50° to 52° F.) were in areas with depths of 55 to 79 feet, whereas temperatures ranged from 52° to 55° F. at the maximum depths of 79 to 85 feet.

Thermal stratification was not well defined at most of the stations near the southern shore. The depths ranged from 26 to 30 feet at these stations. Thermal stratification occurred near the northern shore, however, between Pelee Point and Port Stanley (Tables 1 and 2).

The depth of the thermocline varied considerably from area to area. The upper limits of the thermocline were 50 to 65 feet below the surface in the middle of the central basin. A north-south gradient was apparent in the western part of the central basin. The thermocline started 20 feet below the surface near the north shore and deepened to 40 feet toward the south shore. The depth of water apparently had some influence on the upper limits of the thermocline. At stations with water depths 50 feet and greater the average depth of the upper limit of the thermocline was about 49 feet below the surface. The thermocline started at an average depth of about 28 feet when water depths were less than 50 feet.

Dissolved oxygen.—The concentrations of dissolved oxygen in the western and central basins differed substantially. The waters in the upper strata in the western basin were supersaturated with dissolved oxygen (103 percent) at an average concentration of 8.1 ppm and a surface temperature of 78.7° F. The percentage saturation was somewhat less (76.5 percent) in the water near the bottom where the average dissolved-oxygen content was 6.1 ppm and water temperature was 75.7° F. The difference between the water in the upper strata and bottom, although slight, was significant, since the relatively shallow waters were essentially homothermous. The lowest dissolved-oxygen concentration (2.4 ppm) was at Station 10, 1 mile offshore 5 miles west of Kingsville (Figure 3). Dissolved-oxygen concentrations in the bottom waters in the vicinity of the islands ranged from 6 to 7 ppm.

The dissolved-oxygen content in most of the central basin was less at all depths than in the west end. Despite the slightly cooler waters in the epilimnion (average temperature 76.8° F.) the dissolved oxygen averaged 7.3 ppm—a percentage saturation of 92 percent. The water near the bottom had a percentage

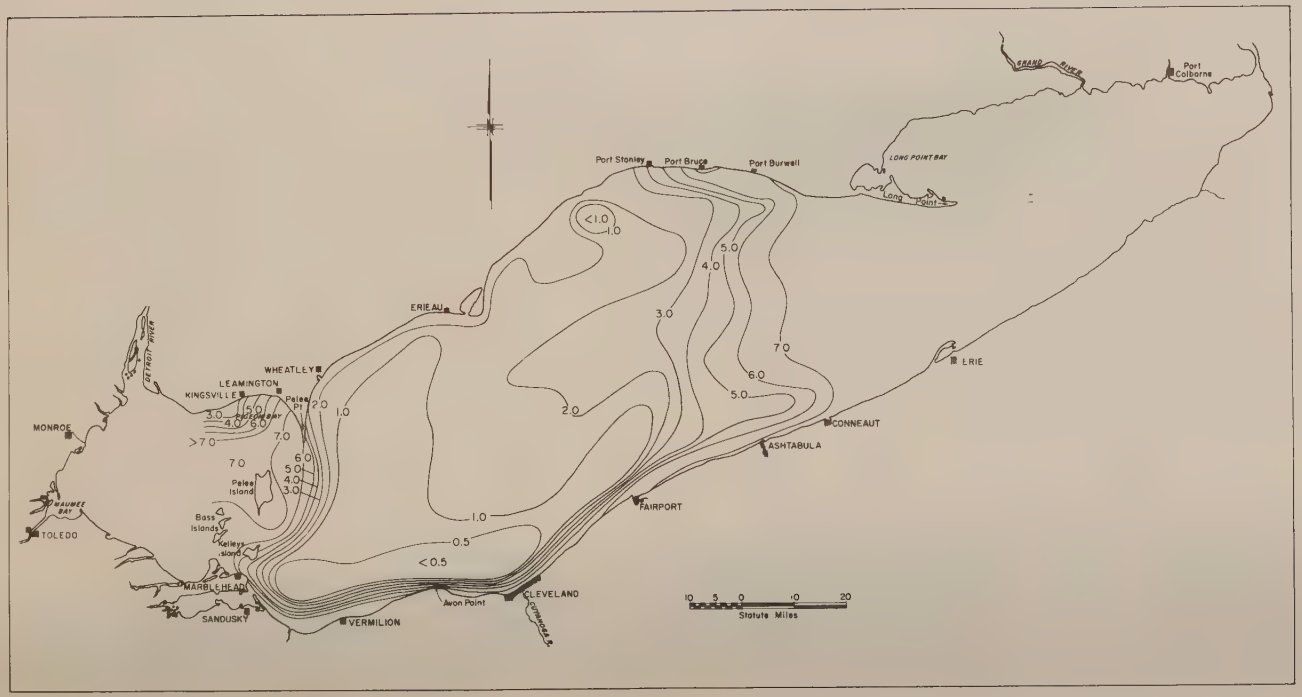

Figure 3.--Distribution of dissolved oxygen in the bottom waters of Lake Erie, 1959. [The eastern and extreme western areas were not sampled.]

saturation of 35 percent, an average dissolved-oxygen concentration of 3.3 ppm, and an average temperature of 60.0° F. A number of stations in the western part of the central basin gave dissolved-oxygen concentrations of less than 1 ppm. The contoured distribution of this oxygen-deficient water indicated that it extended in a band about 10 miles wide from the vicinity of Marblehead to northeast of Fairport (Figure 3). A broad tongue of this same mass extended north almost to the shore near Erieau. If the waters with a dissolved-oxygen content of 3 ppm or less are considered, it appears that about 70 percent of the bottom waters of the central basin had a serious oxygen deficiency. Sampling at 5 stations between Marblehead and Cleveland indicated that the dissolved-oxygen content of the bottom waters was 0.5 ppm or less; no oxygen could be detected at 2 of these stations (21, 48). An isolated instance of very low dissolved-oxygen concentrations occurred near the north shore southwest of Port Stanley. Toward the east from a line between Port Stanley and Fairport the dissolved-oxygen content of the bottom waters gradually increased to about 7 ppm.

Low dissolved-oxygen concentrations were accompanied by pronounced thermal stratification (Tables 1 and 2). In the shallower areas closer to shore where the waters were mostly homothermous, the dissolved-oxygen content was several parts per million greater than at adjacent deeper stations where the water was thermally stratified.

Survey of 1960

Meteorological observations.—During the first day of the survey, winds of 5 to 12 mph from the northwest produced a gentle sea with waves less than 1 foot high. Visibility was good—from 10 to 15 miles over most of the lake--although a light fog lay near the north shore in early morning. The sky was about three-quarters overcast throughout the day. Relative humidity on the lake decreased throughout the day from a high of 89 percent in the morning to a low of 81 percent in mid-afternoon.

Meteorological conditions had changed only slightly the second day of the survey. Calm seas prevailed throughout the lake. Winds of 1 to 5 mph were out of the northeast. The sky was clear to completely overcast. The relative humidity ranged from a high of 76 percent to a low of 66 percent.

The U.S. Weather Bureau records from Cleveland, Ohio, show that for the 7 days prior to the survey the winds averaged

about 6 to 11 mph, mostly out of the southwest. Some winds reached velocities up to 28 mph on August 29. These winds did not last long and probably had little influence on conditions in the lake.

Transparency.--The transparency of the water in the western basin was low; Secchi-disc measurements were 2 to 4 feet. Secchi-disc depths were mostly 20 feet and more in the central basin and the maximum reading was 30 feet. Values were lower towards the island region where the transparency decreased from 20 to 6 feet. Most of the Secchi-disc measurements were around 24 feet in the eastern basin. Transparency was lower in the shallower areas near shore throughout the lake.

Surface temperatures.—Surface temperatures ranged from 71° F. (Station 94) in the eastern basin to 79° F. (Station 27) southeast of Pelee Point (Table 4). Water was warm (78° F.) in the shallows off Vermilion and in an extensive area extending from Monroe to Marblehead including Maumee Bay. Surface waters were cooler near the north shore of the central basin (74° F.) and along both the north and south shores of the eastern basin (71° to 72° F.).

Detroit River water extended from the river mouth almost to the Bass Islands as a forked tongue of cooler water (74°-75° F.). The major mass extended southward almost to Marblehead while a smaller mass protruded into Pigeon Bay.

Temperatures in the western half of the central basin were mostly around 75° F. (Tables 3, 4, and 7). Warmer water (77°-79° F.) extended southeast from Pelee Point. A large mass of surface water with temperatures around 73° F. extended from the east end of the lake into the eastern half of the central basin. Surface temperatures were higher (75°-76° F.) in the shallower areas inside of Long Point. Observations made over 30 hours at Stations 35A and 37 (Figure 2, Tables 5 and 6) show diurnal changes in surface water temperatures of about 2.5° F. On August 30 at Station 35A, temperatures increased from 75.2° F. in the morning to 77.0° F. in the late afternoon, decreased to 74.3° F. by 1400 EST. Temperature changes were similar at Station 37, increasing from 72.5° to 75.0° F. on August 30 and decreasing again to 73.0° F. the morning of August 31. These changes probably reflect the usual daily fluctuations in summer during calm weather. A marked increase in surface temperature from 73.0° to 80.0° F. occurred between 0700 and 1500 EST at Station 37 (Table 5). This increase was probably due to a movement of a warmwater mass into the area from the northeast where temperatures had been 78° and 79° F. earlier that morning at Stations 28 and 27 (Table 4).

Subsurface temperatures.—The water was essentially homothermous in the western basin, although temperatures of the bottom waters were about 1° to 3° F. cooler than those at the surface. The distribution of the subsurface temperatures did not, however, reflect the distribution of surface temperatures. A large mass of 73° F. water occupied the entire western half of the basin. Temperatures were 1° to 2° F. higher among the islands, in Pigeon Bay, and along shore east of Maumee Bay (Tables 3 and 4).

Temperatures were much lower in the central basin where they ranged from 48° to 53° F. in the deeper areas (Tables 3, 4, and 7). A large mass of cool water (49.5° to 52° F.) lay near the bottom in an area which included Stations 35, 37, 52, and 53 (Figure 2). Temperatures gradually increased eastward of this area to a high of 53.5° F. at Station 70, although the depth remained the same, and decreased again farther eastward to a low of 48° F. at Station 76 (Table 4, Figure 2). The low value probably indicates the protrusion, into the central basin, of a mass of colder water from the eastern basin. The lower temperatures in the central basin were in areas with depths of at least 50 feet. The water depth increases just east of the islands to around 42 to 48 feet. Nevertheless, almost the entire area 10 miles east of the islands had water temperatures of about 72° F. Subsurface temperatures were higher along the south shore (75° to 76° F.) than at comparable depths along the north shore (72° to 73° F.).

The temperatures were lowest in the deep waters of the eastern basin. Temperatures were less than 48° F. at stations where depths were greater than 90 feet. A low temperature of 40.8° F. was recorded at Station 93 (Table 4). Temperatures ran higher in the shallower areas; the highest was 74° F. where homothermous conditions existed at Station 89 just east of Erie.

Thermal stratification was limited to water depths of 50 feet or greater except for one shallow station in Long Point Bay (Table 3, Station 81). The depth of the thermocline was around 50 to 60 feet in most areas of the open lake and somewhat closer to the surface in shallower areas near shore. The lower limits of the thermocline extended 20 to 30 feet deeper in the deepest areas of the eastern basin. The hypolimnion existed as a narrow layer extending only 1 to 5 feet above the bottom except in the deepest areas in the central basin and in the eastern basin. The upper limits of the hypolimnion averaged 10.8 feet above the bottom in the central basin. The lower limits of the thermocline ended at the lake bottom at a number of stations; a true hypolimnion did not exist at these stations.

Table 3.--Physical and chemical data for Lake Erie, August 30, 1960

[Bottom refers to immediately above the bottom.]

Station number	Latitude	Longitude	Time (EST)	Depth at station (feet)	Thermocline depth (feet)	Temperature (°F.)		Dissolved oxygen (ppm)			Phenolphthalein alkalinity (ppm $CaCO_3$)			Total alkalinity (ppm $CaCO_3$)			pH			Secchi disc depth (feet)	Specific conductance (K_{18} x 10^6)	
						Surface	Bottom	Surface	Below thermocline	Bottom	Surface	Below thermocline	Bottom	Surface	Below thermocline	Bottom	Surface	Below thermocline	Bottom		Surface	Bottom
9	41°32'20"	82°58'00"	0750	13	None	75.0	75.0	4.2	...	4.5	2	...	3	100	...	103	...	...	...	2.5	238	241
8	41°33'40"	82°58'00"	0830	18	None	75.0	74.5	5.2	...	5.0	4	...	3	102	...	102	...	...	...	3.0	236	238
7	41°42'20"	82°58'00"	1000	32	None	74.0	73.0	4.8	...	4.1	0	...	0	73	...	78	...	...	...	4.5	241	239
6	41°51'10"	82°58'00"	1200	35	None	74.0	72.5	6.9	...	6.5	4	...	0	99	...	97	...	...	...	7.0	213	218
5	41°58'40"	82°58'00"	1400	27	None	75.5	73.0	5.9	...	4.2	3	...	2	103	...	100	...	...	...	6.0	233	241
1A	41°59'20"	83°09'20"	1500	20	None	75.5	73.0	6.2	...	5.9	1	...	2	95	...	96	...	...	...	4.5	...	...
2A	41°55'30"	83°16'20"	1620	22	None	78.0	73.0	5.8	...	4.5	11	...	1	114	...	109	...	...	...	3.0	...	...
23	41°56'10"	82°34'40"	0750	35	None	75.0	73.4	5.7	...	6.2	8	...	10	102	...	107	...	...	...	7.5	247	253
22	41°56'50"	82°34'40"	0810	39	None	75.0	73.4	6.0	...	5.6	0	...	0	72	...	77	...	...	...	6.0	243	249
21	41°30'30"	82°34'40"	0900	39	None	75.0	73.4	6.0	...	3.6	8	...	0	98	...	104	...	...	...	6.0	248	231
20	41°34'30"	82°34'30"	1000	43	None	75.0	73.0	7.2	...	6.4	4	...	8	96	...	98	...	...	...	6.0	225	230
19	41°43'20"	82°35'00"	1100	43	None	75.5	72.5	7.6	...	6.4	9	...	0	96	...	84	...	...	...	8.0	230	226
18	41°51'30"	82°35'00"	1300	31	None	76.5	75.0	7.4	...	6.6	9	...	0	96	...	84	...	...	...	6.5	225	222
17	41°56'40"	82°35'00"	1400	34	None	77.0	74.0	7.4	...	6.6	11	...	6	98	...	92	...	...	...	5.0	225	222
16	42°00'00"	82°36'20"	1500	32	None	78.0	73.5	7.4	...	7.0	11	...	6	98	...	93	...	...	...	5.0	229	257
33	42°11'00"	82°12'00"	0750	40	None	74.0	70.8	7.3	6.0	4.0	...	...	...	...	...	...	...	...	...	8.0	...	...
34	42°08'40"	82°12'00"	0821	60	43-52	74.5	58.0	8.4	...	1.8	...	...	...	...	...	...	...	...	...	18.0	...	...
35	42°00'00"	82°12'00"	0918	67	48-52	74.8	49.5	9.5	8.1	3.3	...	...	...	...	...	...	...	...	...	15.0	...	...
36	41°50'40"	82°12'00"	1024	65	36-42	74.8	49.4	8.1	3.5	3.5	...	...	...	...	...	...	...	...	...	11.5	...	...
38	41°34'00"	82°12'00"	1233	51	47-51	75.0	63.0	8.5	...	7.7	...	...	...	...	...	...	...	...	...	10.0	...	...
39	41°30'00"	82°12'00"	1319	41	None	77.0	74.5	8.9	8.5	5.8	...	...	...	...	...	...	...	...	...	6.5	...	...
40	41°29'00"	82°12'00"	1459	34	None	77.8	76.0	9.3	8.9	8.7	...	...	...	...	...	...	...	...	...	5.0	...	...
57	41°34'00"	81°37'00"	0750	38	None	76.0	75.5	8.3	8.4	8.8	0	4	5	90	92	90	7.6	8.8	8.8	7.5	305	275
56	41°37'10"	81°37'00"	0830	50	None	75.0	73.0	8.3	7.5	7.3	5	4	5	95	90	95	8.8	8.8	8.8	18.0	262	264
55	41°42'40"	81°37'00"	0900	65	50-55	75.0	56.5	8.8	0.3	0.0	7	0	0	96	93	95	8.8	7.6	7.6	25.0	272	264
54	41°51'10"	81°37'00"	1000	75	55-70	75.5	54.5	8.8	1.2	0.5	6	4	6	95	98	99	8.8	...	...	20.0	269	274
53	42°00'00"	81°37'00"	1100	80	60-65	75.0	52.0	8.8	1.6	1.1	...	0	0	...	93	93	...	7.6	7.6	30.0	259	261
52	42°08'30"	81°37'00"	1200	80	60-70	75.0	51.5	8.8	3.6	1.9	0	0	0	89	87	95	8.8	7.8	7.6	30.0	260	260
51	42°17'40"	81°37'00"	1300	75	60-65	75.0	53.5	8.8	3.5	1.1	0	0	0	90	91	91	8.2	7.8	7.6	25.0	263	261

Table 3. --(Continued)

Station number	Latitude	Longitude	Time (EST)	Depth at station (feet)	Thermocline depth (feet)	Temperature (° F.)		Dissolved oxygen (ppm)			Phenolphthalein alkalinity (ppm $CaCO_3$)			Total alkalinity (ppm $CaCO_3$)			pH			Secchi disc depth (feet)	Specific conductance ($K_{18} \times 10^6$)	
						Surface	Bottom	Surface	Below thermocline	Bottom	Surface	Below thermocline	Bottom	Surface	Below thermocline	Bottom	Surface	Below thermocline	Bottom		Surface	Bottom
50	42°25'10"	81°37'00"	1400	65	50-60	75.0	59.5	8.2	4.4	2.5	0	...	0	89	...	90	8.2	...	7.6	20.0	251	254
49	42°28'20"	81°37'00"	1500	35	None	74.0	73.0	8.1	8.0	7.7	4	3	3	93	92	93	8.4	8.2	8.2	20.0	255	252
73	41°55'00"	80°51'00"	0750	40	None	74.0	74.0	7.6	...	7.6	0	0	6	92	93	98	7.6	7.6	...	18.0	256	255
72	42°00'00"	80°51'00"	0815	68	55-63	74.0	55.0	7.5	6.0	1.3	7	0	0	93	94	95	...	7.5	7.5	19.0	256	256
71	42°08'20"	80°51'00"	0935	72	54-60	73.0	54.0	7.4	1.4	1.4	0	...	0	85	...	82	7.6	7.5	7.6	19.0	247	257
70	42°17'00"	80°51'00"	1030	70	53-58	73.0	53.5	7.4	1.8	1.8	8	0	0	96	96	95	...	7.6	7.6	22.0	247	252
89	42°10'20"	87°03'00"	0700	30	None	74.0	74.0	8.2	...	8.2	0	...	5	96	...	105	7.7	...	...	11.0	261	262
88	42°14'10"	87°03'00"	0756	66	54-60	73.0	60.0	...	...	3.1	...	...	...	...	...	...	7.6	...	7.3	22.0	258	260
87	42°17'20"	87°03'00"	0836	67	54-67	72.0	52.0	9.6	...	4.4	...	...	...	...	...	...	7.6	...	7.3	25.0	258	263
86	42°26'10"	87°03'00"	1017	130	60-90	73.0	44.0	...	...	8.8	...	...	...	...	...	...	7.5	...	7.6	24.0	261	262
84	42°34'00"	87°03'00"	1222	173	66-108	74.0	42.5	8.8	...	8.2	...	...	...	...	...	...	7.7	...	7.5	24.0	257	259
83	42°41'40"	87°03'00"	1355	96	48-66	75.0	48.0	...	...	8.6	...	...	...	...	...	...	8.1	...	7.7	24.5	261	264
82	42°43'10"	87°03'00"	1430	73	54-72	76.0	51.5	...	...	...	...	...	...	...	...	...	8.5	...	7.7	24.5	257	270
81	42°46'30"	87°03'00"	1516	38	30-38	75.0	65.0	...	...	...	...	...	...	...	...	...	8.5	...	8.2	19.0	256	262
100	42°33'20"	79°14'00"	0810	64	None	72.5	71.6	8.4	...	8.4	...	...	...	...	...	...	...	...	...	26.0	266	266
99	42°36'40"	79°14'00"	0903	85	60	72.1	51.8	8.5	7.7	6.0	...	...	...	...	...	...	...	...	...	24.0	270	265
98	42°42'00"	79°14'00"	1028	76	65	72.7	53.6	8.4	...	5.3	...	...	...	...	...	...	...	...	...	29.0	267	265
97	42°49'40"	79°14'00"	1150	60	50	72.7	58.1	8.2	...	1.9	...	...	...	...	...	...	...	...	...	28.0	267	274
96	42°51'20"	79°14'00"	1225	25	None	73.4	71.1	8.4	8.4	8.0	...	...	...	...	...	...	...	...	...	18.0	272	268
96A	42°50'00"	79°24'30"	1355	60	45	72.9	62.1	...	...	7.9	...	...	...	...	...	...	...	...	...	22.0	...	...

Table 4. --Physical and chemical data for Lake Erie, August 31, 1960

[Bottom refers to immediately above the bottom.]

Station number	Latitude	Longitude	Time (EST)	Depth at station (feet)	Thermocline depth (feet)	Temperature (°F.)		Dissolved oxygen (ppm)			Phenolphthalein alkalinity (ppm $CaCO_3$)			Total alkalinity (ppm $CaCO_3$)			pH			Secchi-disc depth (feet)	Specific conductance ($K_{18} \times 10^6$)	
						Surface	Bottom	Surface	Below thermocline	Bottom	Surface	Below thermocline	Bottom	Surface	Below thermocline	Bottom	Surface	Below thermocline	Bottom		Surface	Bottom
1	41°59'30"	83°10'00"	0750	16	None	75.0	73.0	4.8	...	4.3	0	...	0	95	...	96	...	...	...	...	288	264
2	41°51'00"	83°10'00"	0905	30	None	76.5	73.5	7.3	...	3.9	7	...	0	103	...	94	...	...	...	...	245	241
3	41°42'00"	83°10'00"	1100	25	None	77.5	73.0	6.5	...	3.1	10	...	0	107	...	98	...	...	...	...	244	245
4	41°38'30"	83°10'00"	1200	13	None	78.5	75.0	6.2	...	6.2	8	...	4	108	...	101	...	...	...	...	242	249
10	41°58'40"	82°47'00"	0750	35	None	76.0	74.0	7.4	...	6.4	14	...	12	98	...	97	...	...	...	6.0	223	221
11	41°55'20"	82°47'00"	0830	36	None	75.0	74.0	7.6	...	6.8	8	...	3	92	...	92	...	...	...	4.5	219	223
12	41°50'20"	82°47'00"	1000	36	None	76.0	73.5	7.6	...	4.4	3	...	0	87	...	92	...	...	...	4.8	225	229
13	41°42'20"	82°46'20"	1200	35	None	78.0	74.0	6.6	...	6.0	12	...	6	95	...	94	...	...	...	4.8	227	228
14	41°37'20"	82°46'00"	1255	33	None	78.0	75.0	7.6	...	5.8	14	...	6	91	...	94	...	...	...	6.2	233	225
15	41°33'40"	82°47'00"	1355	16	None	78.0	75.0	6.6	...	5.0	11	...	6	93	...	93	...	...	...	4.0	237	233
32	41°26'20"	82°23'00"	0744	30	None	76.0	75.2	7.9	...	6.7	...	...	...	...	...	...	...	...	...	8.0	...	...
31	41°27'10"	82°23'00"	0758	42	None	76.0	74.0	8.8	...	5.8	...	...	...	...	...	...	...	...	...	6.5	...	...
30	41°29'40"	82°23'00"	0821	48	None	76.0	73.5	8.0	...	3.1	...	...	...	...	...	...	...	...	...	8.0	...	...
29	41°33'40"	82°23'00"	0859	48	None	75.8	70.8	9.4	...	4.0	...	...	...	...	...	...	...	...	...	6.5	...	...
28	41°42'20"	82°23'00"	1045	45	None	78.0	71.5	8.5	7.3	4.1	...	...	...	...	...	...	...	...	...	10.0	...	...
27	41°50'40"	82°23'00"	1245	40	None	79.0	72.5	9.0	...	8.2	...	...	...	...	...	...	...	...	...	10.0	...	...
26	41°59'40"	82°23'00"	1445	47	None	77.0	72.0	9.2	...	8.2	...	...	...	...	...	...	...	...	...	15.0	...	...
25	42°03'00"	82°23'00"	1512	41	None	77.0	72.0	8.8	...	7.3	...	...	...	...	...	...	...	...	...	11.5	...	...
24	42°05'20"	82°23'00"	1541	30	None	76.5	71.0	9.2	...	7.0	...	...	...	...	...	...	...	...	...	11.5	...	...
41	42°15'00"	82°00'00"	0750	35	None	76.0	73.0	8.6	8.0	7.7	4	4	2	90	91	92	8.4	8.4	8.4	...	256	253
42	42°11'20"	82°00'00"	0830	57	35-55	76.0	62.0	8.7	7.8	7.8	2	0	0	90	88	89	8.4	7.6	7.6	...	261	258
43	42°08'20"	82°00'00"	0900	65	50-55	75.0	54.5	8.4	3.9	2.4	5	0	0	35	95	95	8.4	7.6	7.6	...	256	260
44	42°00'00"	82°00'00"	1000	75	50-60	75.0	50.5	7.7	1.8	1.2	6	0	0	92	93	95	8.4	7.6	7.6	...	263	260
45	41°51'00"	82°00'00"	1100	75	35-60	76.0	49.5	7.9	7.0	2.8	8	0	0	98	95	95	8.4	7.8	7.6	...	262	259
46	41°42'30"	82°00'00"	1200	74	50-55	76.5	51.0	7.1	5.5	2.0	7	0	0	97	95	94	8.4	7.6	7.6	...	259	261
47	41°33'40"	82°00'00"	1300	53	45-53	76.0	53.0	8.1	0.6	0.7	6	0	0	96	93	92	8.4	7.6	7.6	...	248	261
48	41°32'00"	82°00'00"	1445	30	None	77.0	76.0	8.9	7.6	7.8	6	7	6	96	97	94	8.4	8.4	8.4	...	255	264

(Continued)

Table 4. --(Continued)

Station number	Latitude	Longitude	Time (EST)	Depth at station (feet)	Thermocline depth (feet)	Temperature (° F.)		Dissolved oxygen (ppm)			Phenolphthalein alkalinity (ppm $CaCO_3$)			Total alkalinity (ppm $CaCO_3$)			pH			Secchi disc depth (feet)	Specific conductance $K_{18} \times 10^6$	
						Surface	Bottom	Surface	Below thermocline	Bottom	Surface	Below thermocline	Bottom	Surface	Below thermocline	Bottom	Surface	Below thermocline	Bottom		Surface	Bottom
74	42°33'00"	80°26'00"	0915	39	None	73.5	72.0	...	...	...	...	...	...	...	...	...	8.4	...	8.2	10.0	255	254
75	42°29'20"	80°26'00"	1000	50	48-50	74.0	66.0	...	...	...	...	...	...	...	...	...	8.6	...	8.5	19.5	254	253
76	42°24'30"	80°26'00"	1030	77	66-77	74.0	48.0	...	...	5.3	...	...	...	...	...	...	8.5	...	7.9	21.0	255	259
77	42°15'20"	80°26'00"	1148	66	48-66	73.0	60.0	9.7	...	8.5	...	...	...	...	...	...	8.5	...	8.5	21.0	257	261
78	42°07'00"	80°26'00"	1245	45	None	73.0	67.0	8.8	...	9.5	...	...	...	...	...	...	8.3	...	8.6	21.5	255	254
80	42°02'40"	80°26'00"	1330	40	None	73.5	71.0	...	...	...	...	...	...	...	...	...	8.3	...	8.2	...	260	257
90	42°49'30"	79°37' 00"	0720	35	None	72.5	72.5	8.0	...	8.0	...	...	...	...	...	...	...	...	...	22.0	275	265
91	42°46'00"	79°37'00"	0819	85	68	72.7	48.9	8.2	4.7	5.2	...	...	...	...	...	...	...	...	...	27.0	267	272
92	42°41'30"	79°37'00"	0920	103	65	72.7	46.9	8.5	7.2	3.4	...	...	...	...	...	...	...	...	...	28.0	246	268
93	42°33'00"	79°37'00"	1100	166	65	73.8	40.8	8.4	6.6	8.9	...	...	...	...	...	...	...	...	...	30.0	270	271
94	42°24'30"	79°37'00"	1244	122	60	71.1	43.0	8.4	7.2	7.7	...	...	...	...	...	...	...	...	...	29.0	265	265
95	42°20'30"	79°37'00"	...	30	...	...	...	8.0	...	8.2	...	...	...	...	...	...	...	...	...	22.0	279	265

Table 5.--Physical and chemical data from Station 37 in Lake Erie, 1960

[Latitude 41°42'00"N, Longitude 82°12'00"W. Depth at station, 60 feet.
Bottom refers to immediately above the bottom.]

Date and time (EST)	Thermocline depth (feet)	Temperature (°F.)		Dissolved oxygen (ppm)		Phenolphthalein alkalinity (ppm $CaCO_3$)			Total alkalinity (ppm $CaCO_3$)			pH			Secchi-disc depth (feet)	Specific conductance ($K_{18} \times 10^6$)	
		Surface	Bottom	Below thermocline	Bottom	Surface	Below thermocline	Bottom	Surface	Below thermocline	Bottom	Surface	Below thermocline	Bottom		Surface	Bottom
August 30																	
0750	40-45	72.5	50.1	0.7	1.0	10	0	0	99	93	85	8.4	7.0	7.0	12	...	...
0810	41-45	72.5	50.2	0.6	0.6	6	0	0	88	98	100	8.4	7.0	7.0	12	...	...
0830	39-45	72.5	50.1	0.7	0.7	5	0	0	100	100	95	8.4	7.0	7.0	13	...	...
0900	39-44	72.5	50.2	0.8	2.0	6	0	0	98	103	100	8.4	7.0	7.0	13	...	...
1000	39-42	73.0	50.2	1.3	2.4	5	0	0	98	100	98	8.4	7.0	7.0	13	...	...
1100	39-45	73.0	50.1	1.5	1.8	6	0	0	100	101	102	8.4	7.0	7.0	13	...	...
1200	39-43	73.8	50.1	1.9	2.0	3	0	0	102	99	109	8.4	7.0	7.0	13	253	247
1300	39-45	73.8	50.2	4.0	1.5	5	0	0	104	103	103	8.4	7.2	7.0	13	...	...
1400	40-45	74.3	50.6	3.2	2.0	5	0	0	100	106	104	8.4	7.2	7.0	12	...	...
1500	39-44	74.2	50.2	3.2	2.9	8	0	0	102	105	95	8.4	7.2	7.0	12	...	...
1600	39-42	74.2	50.5	2.6	2.9	2	0	0	94	101	100	8.4	7.2	7.0	13	244	255
1700	35-43	75.0	50.6	3.2	2.0	2	0	0	94	95	98	8.4	7.2	7.0	12	...	...
1800	41-45	74.2	51.0	1.7	1.2	1	0	0	91	95	101	8.4	7.0	7.0	...	...	...
1900	40-44	74.0	51.0	0.9	0.8	4	0	0	94	78	77	...	...	...	...	...	...
2000	41-44	74.0	50.9	0.9	0.9	1	0	0	88	102	94	8.4	7.2	7.2	...	247	251
2100	40-44	74.0	50.8	2.7	1.0	4	0	0	103	100	100	...	...	...	...	...	...
2200	40-45	73.8	51.1	0.5	0.9	8	0	0	99	105	100	...	...	...	...	...	...
2300	41-47	73.6	51.1	0.9	0.9	2	0	0	92	80	86	8.4	7.2	7.2	...	...	...
August 31																	
0000	44-46	73.5	51.1	2.6	1.1	5	0	0	100	105	106	8.4	7.4	7.2	...	253	250
0100	42-45	73.3	51.0	4.7	1.1	8	0	0	101	105	107	8.9	7.4	7.2	...	...	...
0200	42-46	73.2	50.8	1.9	1.4	4	0	0	107	100	103	...	...	...	...	...	...
0300	42-46	73.1	51.1	3.0	1.2	5	0	0	105	105	107	8.6	7.3	7.1	...	...	...
0400	41-44	73.3	51.0	3.6	0.7	5	0	0	109	107	104	...	...	...	...	243	254
0500	44-46	73.1	51.0	0.8	1.1	4	0	0	106	98	97	8.5	7.2	7.1	...	...	...

(Continued)

Table 5. --(Continued)

Date and time (EST)	Thermocline depth (feet)	Temperature (° F.)		Dissolved oxygen (ppm)		Phenolphthalein alkalinity (ppm $CaCO_3$)			Total alkalinity (ppm $CaCO_3$)			pH			Secchi disc depth (feet)	Specific conductance ($K_{18} \times 10^6$)	
		Surface	Bottom	Below thermocline	Bottom	Surface	Below thermocline	Bottom	Surface	Below thermocline	Bottom	Surface	Below thermocline	Bottom		Surface	Bottom
0600	41-46	73.1	51.0	0.8	1.1	5	0	0	105	97	95	...	...	...	...	...	...
0700	42-50	73.0	51.0	3.2	0.7	5	0	0	99	99	98	8.4	7.4	7.0	...	...	...
0750	40-51	73.2	51.3	4.7	0.8	1	0	0	94	95	92	8.4	7.2	7.1	12	245	253
0810	40-46	73.1	51.0	1.0	0.8	11	0	0	101	103	101	...	...	...	14	...	...
0830	42-45	73.1	51.0	1.0	0.6	5	0	0	100	103	100	8.6	...	...	14	...	...
0900	40-46	73.2	51.0	0.6	0.5	9	0	0	102	102	100	8.6	...	...	14	...	...
1000	42-46	73.8	51.1	0.3	0.5	2	0	0	96	101	100	8.5	...	...	14	...	...
1100	42-45	74.5	51.0	2.2	0.4	3	0	0	96	99	98	...	...	...	13	...	...
1200	42-45	76.0	51.0	0.9	0.6	7	0	0	95	102	100	...	...	...	13	247	253
1300	42-45	78.0	51.4	0.4	0.3	3	0	0	96	101	98	...	...	...	12	...	...
1400	42-43	79.0	51.4	0.5	0.2	3	0	0	98	99	100	...	...	...	12	...	...
1500	43-45	80.0	51.5	0.4	0.3	4	0	0	95	99	100	...	...	...	14	242	250

Table 6.—Physical and chemical data from Station 35A in Lake Erie, 1960

[Latitude 42°04' 00"N, longitude 82°12' 00"W. Depth at station 62-65 feet. Bottom refers to immediately above the bottom.]

Date and time (EST)	Thermocline depth (feet)	Temperature (° F.)		Dissolved oxygen (ppm)			Secchi-disc depth (feet)
		Surface	Bottom	Surface	Below thermocline	Bottom	
August 30							
0750	50-56	75.2	50.6	7.8	1.0	0.7	24.5
0825	50-56	75.3	50.8	...	...	...	24.5
0900	50-56	75.2	51.5	6.5	1.0	0.6	23.0
1000	50-56	76.1	50.8	...	...	...	23.0
1100	50-56	75.2	50.3	...	...	...	23.0
1200	50-57	75.9	50.5	...	...	...	23.0
1300	50-56	77.0	50.8	7.9	0.9	0.8	21.0
1400	50-55	77.0	50.5	...	...	...	21.0
1500	50-57	77.0	51.0	...	...	...	21.0
1600	50-58	77.0	51.0	...	...	...	21.0
1700	50-56	77.0	50.6	8.1	1.0	0.6	19.5
1800	50-56	77.0	50.8	...	...	...	19.5
1900	50-56	76.1	51.0	...	...	...	...
2000	50-56	75.9	50.6	...	...	...	...
2100	49-57	74.8	51.0	8.4	1.1	0.9	...
2200	50-57	74.3	51.0	...	...	...	...
2300	50-57	74.3	51.0	...	...	...	...
August 31							
0000	50-57	74.3	51.0	...	...	...	...
0100	50-58	72.3	51.3	8.2	1.0	...	...
0200	50-57	75.2	51.0	...	...	...	...
0300	50-58	75.2	51.0	...	...	...	...
0400	50-57	75.2	51.0	...	...	...	...
0500	51-58	73.4	51.0	8.1	0.8	0.4	...
0600	50-58	75.2	51.1	...	...	...	...
0700	50-57	74.3	51.0	...	...	...	...
0750	50-57	74.3	51.0	8.3	0.6	0.4	...
0810	50-57	74.3	51.2	...	...	...	...
0830	50-57	74.7	51.1	...	...	...	...
0900	50-57	74.9	51.0	...	...	...	...
1000	50-58	75.2	50.6	8.1	1.4	1.2	...
1100	50-56	76.8	50.0	...	...	...	...
1200	50-57	77.0	50.5	...	...	...	...
1300	50-58	77.0	51.3	...	...	...	...
1400	50-57	77.3	51.0	8.1	1.0	0.8	...
1500	50-56	77.3	51.0	...	...	...	...

Table 7.—Physical and chemical data collected in central Lake Erie by the C.M.S. *Porte Dauphine*, August 30-31, 1960

[Bottom refers to immediately above the bottom.]

Station number	Date and time (EST)	Latitude (North)	Longitude (West)	Depth at station (feet)	Thermocline depth (feet)	Temperature (° F.)		Dissolved oxygen at surface (ppm)
						Surface	Bottom	
	August 30							
1D	0100	41°58' 00"	81°53' 00"	89	63-75	74.5	51.0	6.8
2D	0130	41 55 48	81 52 00	83	63-75	74.5	51.9	...
3D	0200	41 53 18	81 50 42	84	63-75	74.5	50.6	5.7
4D	0230	41 50 48	81 49 30	85	60-74	74.5	50.0	...
5D	0300	41 48 36	81 48 30	85	60-70	74.5	49.5	6.9
6D	0330	41 46 18	81 46 30	83	58-65	74.5	51.5	...
7D	0400	41 43 42	81 45 42	82	56-65	74.3	51.3	7.1
8D	0430	41 41 30	81 44 00	78	56-75	74.0	53.0	...
9D	0500	41 38 42	81 42 00	68	55-60	74.0	56.0	7.0
10D	0530	41 37 18	81 41 30	59	50-59	74.0	60.1	...
11D	0600	41 34 30	81 40 30	55	40-47	74.3	72.3	6.7
12D	0630	41 34 36	81 37 42	50	...	74.0	73.8	...
13D	0700	41 37 42	81 33 48	40	...	74.0	74.0	7.1
14D	0730	41 40 48	81 27 18	50	...	74.0	74.0	...
15D	0800	41 43 30	81 23 00	40	...	75.0	75.0	7.6
16D	0830	41 46 54	81 17 18	62	...	75.0	74.0	...
17D	0900	41 49 06	81 12 42	54	40-54	74.3	65.0	7.1
18D	0930	41 51 12	81 14 00	73	50-65	74.2	55.5	...
19D	1000	41 53 42	81 15 36	75	55-65	74.3	55.0	7.2
20D	1030	41 55 36	81 16 42	82	50-70	74.0	54.2	...
21D	1100	41 59 18	81 17 36	85	55-65	74.0	54.0	5.6
22D	1130	42 01 42	81 18 12	85	50-70	74.2	53.5	...
23D	1200	42 03 54	81 20 00	85	55-75	74.5	53.0	7.3
24D	1230	42 06 24	81 21 12	85	55-75	74.5	53.0	...
25D	1300	42 08 45	81 22 30	85	58-70	74.5	54.5	7.6
26D	1330	42 11 25	81 23 50	86	65-80	74.9	56.0	...
27D	1400	42 14 00	81 25 00	86	65-80	75.0	57.0	8.1
28D	1430	42 16 20	81 26 15	85	70-80	75.0	63.0	8.1
29D	1500	42 18 50	81 27 20	85	75-85	75.0	64.5	8.9
30D	1530	42 19 45	81 23 30	83	77-80	75.0	68.0	...
31D	1600	42 21 40	81 19 00	81	65-80	75.2	78.0	5.9
32D	1630	42 23 50	81 13 15	80	70-80	75.1	65.0	...
33D	1700	42 24 00	81 10 54	77	60-75	75.1	64.2	7.6
34D	1730	42 21 18	81 06 06	74	65-74	75.0	62.0	...
35D	1800	42 19 00	81 05 18	76	65-76	75.0	62.2	7.1
36D	1830	42 17 18	81 04 24	78	65-75	74.9	59.0	...
37D	1900	42 15 36	81 03 54	78	65-78	74.9	58.0	6.5
38D	1930	42 14 12	81 03 36	80	65-75	74.8	57.0	...
39D	2000	42 12 06	81 03 00	75	65-70	74.3	58.0	6.5
40D	2030	42 10 00	81 01 42	78	65-75	74.2	59.0	...
41D	2100	42 07 18	81 01 00	78	63-70	74.2	57.0	7.5
42D	2130	42 05 12	80 59 48	78	65-75	74.2	56.0	...
43D	2200	42 03 36	80 58 54	78	65-75	74.2	55.0	7.5
44D	2230	42 01 06	80 57 48	78	65-72	74.2	54.2	...
45D	2300	41 58 36	80 57 00	75	56-70	74.2	52.0	7.1
46D	2330	41 56 42	80 56 48	67	52-67	74.2	55.5	...
	August 31							
47D	0000	41 54 12	80 55 18	64	...	74.5	70.5	6.7
48D	0030	41 55 35	80 51 50	58	50-56	74.1	66.0	...
49D	0100	41 46 45	80 49 25	62	50-58	74.4	59.5	7.8
50D	0130	41 59 05	80 49 30	73	60-70	74.0	54.9	...

(Continued)

Table 7.—(Continued)

Station Number	Date and time (EST)	Latitude (North)	Longitude (West)	Depth at Station (feet)	Thermocline depth (feet)	Temperature (° F.)		Dissolved oxygen at surface (ppm)
						Surface	Bottom	
51D	0200	42°01' 05"	80°51' 00"	76	60-70	74.0	54.8	7.5
52D	0230	42 03 50	80 51 45	77	58-72	74.0	56.5	...
53D	0300	42 06 30	80 52 30	80	60-75	73.9	54.0	7.9
54D	0330	42 09 12	80 53 24	78	55-70	73.7	54.0	...
55D	0400	42 11 18	80 54 30	76	55-70	73.5	53.0	7.0
56D	0430	42 13 36	80 55 30	74	60-70	73.5	54.5	...
57D	0500	42 16 00	80 56 15	77	50-70	73.5	55.0	7.0
58D	0530	42 18 00	80 57 00	75	60-71	73.5	55.0	...
59D	0600	42 20 30	80 58 15	76	65-70	73.7	55.8	7.6
60D	0630	42 22 30	80 59 18	74	55-65	73.5	57.0	...
61D	0700	42 25 00	81 00 00	70	60-66	73.4	57.2	6.8
62D	0730	42 27 54	81 01 24	68	60-68	73.4	59.2	...
63D	0800	42 30 24	81 02 06	65	57-65	73.4	62.0	7.4
64D	0830	42 32 30	81 03 24	60	55-60	73.2	63.0	...
65D	0900	42 35 06	81 04 06	54	48-54	73.4	63.0	7.1
66D	0930	42 37 12	81 05 00	40	35-40	73.6	68.6	...
67D	1000	42 37 42	81 01 54	34	...	73.2	73.1	6.9
68D	1030	42 37 36	80 58 24	35	...	74.2	72.0	...
69D	1100	42 37 00	80 56 12	49	42-49	74.2	63.0	7.7
70D	1130	42 34 30	80 55 30	61	50-56	74.4	60.0	...
71D	1200	42 32 00	80 53 42	71	50-60	75.3	61.0	8.1
72D	1230	42 30 00	80 54 00	78	55-60	75.9	60.0	...
73D	1300	42 27 00	80 53 00	78	55-65	76.5	58.0	7.4
74D	1330	42 25 00	80 52 12	90	60-70	76.9	56.0	...
75D	1400	42 22 00	80 51 18	80	60-70	77.5	54.8	7.7
76D	1430	42 26 06	80 50 42	82	60-68	77.3	53.0	...
77D	1500	42 30 30	80 49 30	80	55-60	76.3	62.0	7.1
78D	1600	42 32 30	80 49 06	60	55-57	76.0	61.2	7.8
78D	1700	42 32 30	80 49 06	65	51-57	76.0	61.0	6.9
78D	1800	42 32 30	80 49 06	60	49-56	76.7	60.8	7.9
78D	1900	42 32 30	80 49 06	59	50-55	75.5	60.5	7.0
78D	2000	42 32 30	80 49 06	60	50-55	75.1	60.1	8.2
78D	2100	42 32 30	80 49 06	60	52-55	75.1	60.8	7.9
78D	2200	42 32 30	80 49 06	60	50-55	75.0	60.5	6.9
78D	2300	42 32 30	80 49 06	60	50-56	74.6	61.0	7.7

The closeness of the thermocline to the bottom made it difficult to obtain water samples from the hypolimnion for dissolved-oxygen determinations.

Some slight changes were measured in water temperatures near the bottom at Stations 35A and 37 over 30 hours. No significance can be attached to these changes, however, since they were inconsistent and the depth of the thermocline remained stable at both stations throughout the observation period.

Specific conductance at the surface.—The specific conductance of the surface waters ranged from 213 to 305 μmhos. The values were lowest in the western basin. The higher values were at several stations near shore, especially off river mouths. The highest conductivity (305 μmhos) was at Station 57 (Figure 2) northeast of Cleveland; it probably reflects the outflow of the Cuyahoga River. Values were high also at Station 90 (275 μmhos) off the mouth of the Grand River, Station 96 (272 μmhos) off Port Colborne, and at Station 95 (Tables 3 and 4).

The lowest conductivity was in the main outflow of the Detroit River, *i.e.*, the outflow from midchannel. This mass of low-conductivity water (about 220 μmhos) fanned out in a southeasterly direction from the river mouth and roughly followed the distribution of surface temperatures. Conductance probably was higher along both shores at the river mouth since the conductivities at Stations 1 and 5 were 288 and 233 μmhos (Tables 3 and 4).

Sampling in this area by the Bureau of Commercial Fisheries since the 1960 synoptic survey has shown that the waters in the shipping channel have much lower conductivity than waters along both shores. The International Joint Commission (1951) reported a similar distribution of chlorides during its 1946-48 survey.

The conductivity of surface waters among the islands averaged around 225 mhos. This water probably extended southeast from the islands to Station 20 (Figure 2). Conductivity was higher (241-245 μmhos) in waters of the Maumee Bay area extending from the vicinity of Monroe to Station 7 (Figure 2).

The specific conductance of surface waters in most of central basin was around 250 μmhos, although a large mass of water with conductivity of 260 to 272 μmhos occupied the area between Cleveland and Erieau.

A low specific conductance of 246 μmhos at Station 92 in the eastern basin probably indicated the presence of a lens of low-conductivity water, since the conductivity increased in all directions from this station.

The distribution of surface temperatures and conductivity values did not coincide in the central and eastern basins.

Specific conductance of subsurface waters.—The distribution of the conductivity of the subsurface waters agreed in general with that described for surface waters. Such differences as did exist between the conductivity of surface and bottom waters usually were so slight as to be attributable to error in measurement. An average of all specific-conductance measurements made on subsurface water samples was 253 μmhos. An identical average was obtained for the surface waters.

The distribution of the conductivity of bottom waters differed from that of the surface waters in two ways. The highest conductivity values were not off rivers except for Station 57 near Cleveland (Table 3). The specific conductance of 275 μmhos at this station was the highest recorded for bottom waters, but nevertheless it was lower than the 305 μmhos at the surface. Evidently the river waters and their associated higher conductivity were warmer than the lake and flowed out into the surface layer. The distribution of subsurface water of higher conductivity in the eastern basin was different from that described for the surface waters. The highest values (268-271 μmhos) were in the deepest waters including the areas where values were low at the surface. It appears that a mass of high-conductivity water occupied most of the basin but had an isolated lens of lower conductivity surface water floating in its midst. The distribution of the high-conductivity water approximated the distribution of the cooler waters. A tongue of this water extended into the central basin to Station 77 north of Conneaut (Figure 2).

Total alkalinity at the surface.—All of the vessels did not make determinations for total alkalinity (ppm $CaCO_3$), and the accuracy of the method employing the methyl-orange indicator does not permit attaching any significance to differences of a few parts per million. Nevertheless, data for the western basin and most of the central basin (Tables 3, 4, and 5) appear to show some differences.

Values were low—95 ppm or less--in the Detroit River outflow extending into the island region. Values were higher, 100 ppm or greater, in the Maumee Bay area including Station 2A near Monroe which had a high of 114 ppm and extending almost to Marblehead to Stations 8 and 9 (Figure 2). In general the distribution of alkalinity agreed with that described for surface conductivity.

Most of the total alkalinity values in the central basin were around 95 ppm. An area with concentrations of around 90 ppm extended from the north shore near Erieau out to and including Stations 42 and 52 (Tables 3 and 4).

Total alkalinity of subsurface waters.—Total alkalinity concentrations in most of the western basin ranged from 92 ppm to 97 ppm. Values were slightly higher (98 ppm to 109 ppm) in the Maumee Bay area. A low value of 78 ppm occurred at Station 7 immediately west of the Bass Islands. Concentrations of 84 ppm were determined at Stations 18 and 19 just east of Pelee Island.

Total alkalinity ranged from 82 ppm to 107 ppm in the central basin, but most of the values were around 95 ppm. Concentrations were greater than 100 ppm off of Marblehead and Erie at Stations 21, 23, and 89 (Table 3).

Phenolphthalein alkalinity at the surface.—Phenolphthalein alkalinity (less than 4 ppm as calcium carbonate) was low in the main outflow of the Detroit River. These values generally were low where conductivity and temperature were low. Values were higher (8-11 ppm) off Monroe and east of Maumee Bay at Stations 2A, 3, and 4 (Tables 3 and 4, Figure 2). The highest values (12-14 ppm) were in the vicinity of the islands.

The distribution of specific conductance and phenolphthalein alkalinity in the central basin generally agreed. The highest concentrations were usually in water where the specific conductance was 260 μmhos or greater. Values ranged from 5 to 8 ppm along the southern shore and from 2 to 4 ppm near the northern shore. Isolated low values at several points on the southern shore (off Cleveland, Ashtabula, and Erie) seemed to occur in the outflow from rivers and harbors.

Phenolphthalein alkalinity in subsurface waters.—Phenolphthalein alkalinity was present in subsurface waters at only a few stations where the water was not stratified thermally. Phenolphthalein changes color at a pH of 8.3. The pH of most bottom-water samples from stratified areas was 8.0 or less. In general the pH was around 8.4 in the surface waters and decreased to 8.0 or less immediately below the thermocline (Tables 3 and 4). Evidently Detroit River water near the bottom in the western basin also had a pH less than 8.3, since the bottom waters extending from the mouth of the river and into the central basin did not have any phenolphthalein alkalinity. Phenolphthalein alkalinity of 6 ppm occurred at Stations 13-15 among the islands and in Pigeon Bay at Stations 16 and 17 (Figure 2, Tables 3 and 4). A high value of 12 ppm was recorded at Station 10 in Pigeon Bay off Kingsville, Ontario. Concentrations were 5 to 10 ppm along the southern shore at Stations 23, 46, 56, 57, and 73 (Tables 3 and 4).

Hydrogen-ion concentration.--The data on distribution of pH are incomplete, since all vessels did not make determinations.

Most of the pH measurements were on waters from the central basin. The accuracies of the various instruments used for the determinations were not the same, but nevertheless some general conclusions can be drawn.

The pH of the surface waters ranged from 7.5 to 8.8 and averaged 8.2. The lowest values in the central basin were near shore, usually in homothermous water, off Ashtabula, Cleveland, and Erieau. Most of the surface waters in the central basin had a pH of 8.2 to 8.8.

The hypolimnetic waters had an average pH of about 7.6. The pH of the bottom waters at Stations 74-80 ranged from 7.9 to 8.6. These stations were all on or in the immediate vicinity of the shoal which extends from near Erie to about the middle of Long Point. The water depth above the shoal is 42 to 48 feet whereas the water depth on either side of the shoal is 66 to 78 feet. Consequently, the thermocline extended almost to or to the bottom at these stations and a true hypolimnion did not exist. Therefore, the pH of the bottom waters was almost the same as that measured at the surface (Table 4).

The pH of the surface waters (average 7.9) in the eastern basin was only slightly higher than that of the hypolimnetic waters (average 7.6).

Dissolved oxygen.—Several observations were made of dissolved-oxygen concentrations in the bottom waters prior to the 1960 synoptic survey. The Bureau of Commercial Fisheries found dissolved-oxygen concentrations of only 0.5 ppm in an area about 2 miles east of Marblehead on July 12. On June 14 the concentration had been 6.6 ppm. This area is where Wright (1955) found a low concentration of 0.8 ppm in 1930. The Ohio Division of Wildlife reported dissolved-oxygen concentrations of 2 ppm east of Kelleys Island on July 13. Concentrations of 1.1 ppm and 0.4 ppm occurred in water 50 feet deep off Vermilion July 27 and August 5 (personal communication). The decrease in the dissolved-oxygen content of the bottom waters apparently was less rapid near the north shore of the central basin. The Ontario Department of Lands and Forests established a station 10 miles from Wheatley, Ontario, on a course of 95°. The dissolved-oxygen concentration in the hypolimnion decreased from 8.1 ppm on July 7 to 6.8 ppm on July 21 to 5.7 ppm on August 5, and was 2.6 ppm on August 18 (personal communication).

The average dissolved-oxygen content of the waters in the island area of the western basin was similar to that in 1959. The percentage saturation of dissolved oxygen in the surface waters was 92 percent (dissolved oxygen at an average concentration of 7.3 ppm and a temperature of 77° F.). An

average dissolved-oxygen content of 6.0 ppm at a temperature of 74.1° F. gave a saturation of 73 percent for the bottom waters at Stations 10-17 (Tables 3 and 4).

The shallow waters west of the islands had relatively low dissolved-oxygen content (Figure 4). The average concentration in the surface water was 5.8 ppm and 72 percent saturated at an average temperature of 75.9° F. Despite the lack of thermal stratification, the temperatures showed a gradual decrease from an average of 75.9° F. at the surface to an average of 73.5° F. at the bottom, the average dissolved-oxygen content of the bottom waters was only 4.7 ppm at Stations 1-9, 1A, and 2A (Tables 3 and 4). At 73.5° F. this gave a saturation of only 57 percent. Even the waters in or near the mouth of the Detroit River had dissolved-oxygen concentrations of only 4 to 5 ppm despite the considerable mixing characteristic of this area.

The surface waters of the central basin were supersaturated at 102 percent--average dissolved-oxygen content of 8.3 ppm and an average temperature of 75.3° F. Percentage saturation of dissolved oxygen ranged up to 117 percent at Stations 27, 35, 39, and 40 (Tables 3 and 4).

The average dissolved-oxygen concentration in the bottom waters at all the stations in the central basin was 4.8 ppm. At an average temperature of 64.8° F. this value represents a saturation of 54 percent. The average percentage saturation for those stations that were thermally stratified was 28 percent (average dissolved-oxygen concentration 2.8 ppm, temperature 54.7° F.). The oxygen minima was always near the bottom throughout the central basin.

The dissolved-oxygen conditions of the bottom waters in 1960 and of 1959 showed several differences. The size of the areas included by the 3 ppm contours was approximately the same in both years (Figures 3 and 4). The area of lowest concentration was farther to the east in 1960, however, than in 1959. The lowest dissolved-oxygen concentrations were near the southern shore between Avon Point and Ashtabula in 1960, whereas the lowest concentrations in 1959 were between Marblehead and Cleveland. Only Stations 54 and 55 (Table 3) had dissolved-oxygen concentration of 0.5 ppm or less in 1960, although nine stations had concentrations around 1.0 ppm (Tables 3-6). Consequently, a 0.5 ppm contour was not drawn for the 1960 data.

The area immediately east of Marblehead, where very low dissolved-oxygen concentrations have been found repeatedly (only 0.5 ppm was reported on July 12), had concentrations of 4 to 5 ppm. It is likely, however, that the distribution of the

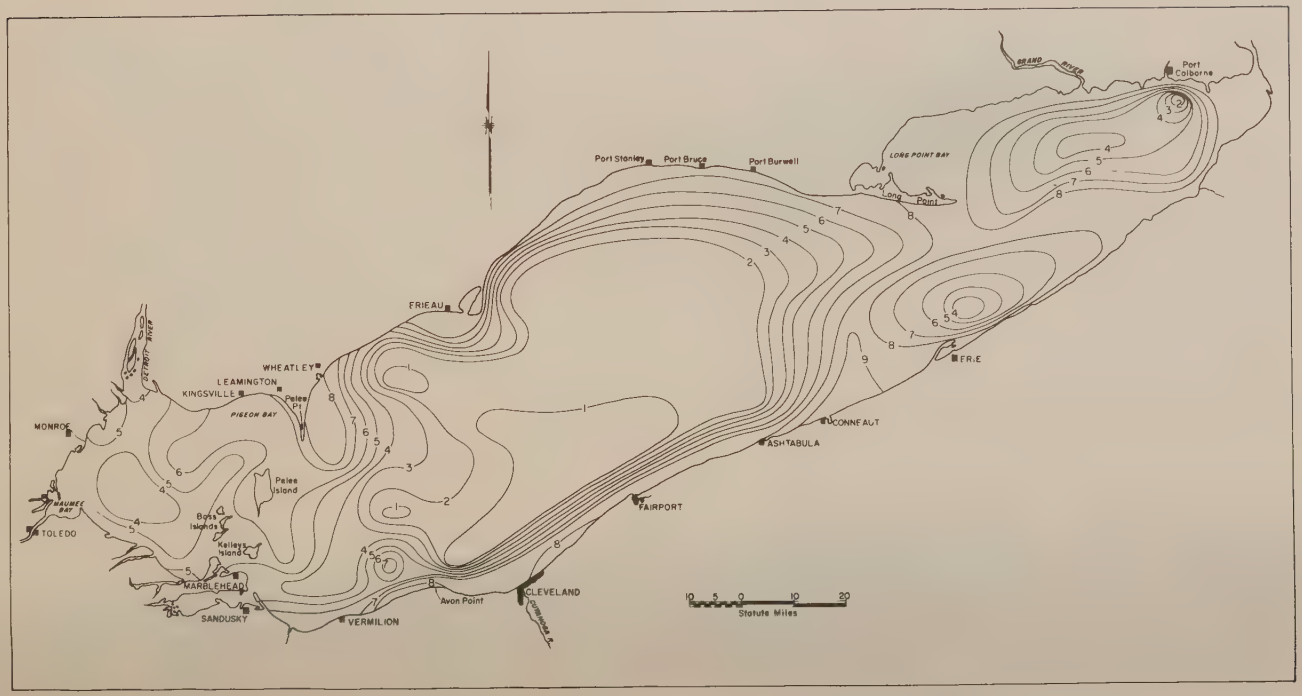

Figure 4.—Distribution of dissolved oxygen in the bottom waters of Lake Erie, 1960.

water with low dissolved-oxygen content does not necessarily indicate areas in which deoxygenation occurs. The oxygen-deficient water mass situated off of Cleveland and Fairport (Figure 4) may have originated farther west to be displaced by the inflowing river water and the seiches, which are especially pronounced in Lake Erie. The occurrence of dissolved-oxygen concentration of 1 ppm or less off Vermilion in late July and early August provides some evidence for this speculation.

Dissolved-oxygen concentrations in the surface waters of the eastern basin were closely similar to those of the central basin and averaged 8.4 ppm at an average temperature of 73.2° F. Consequently, the percentage saturation was 102 percent. The dissolved-oxygen content of the bottom waters of the eastern basin was greater, however, than in the central basin. The average oxygen content of the hypolimnetic waters was 6.1 ppm, giving a saturation of 59 percent at an average temperature of 51.9° F. (Tables 3 and 4). Dissolved-oxygen concentrations were less than 4 ppm only at Stations 88 and 97, off Port Colborne and Erie (Figure 4, Table 3).

The few determinations of the dissolved-oxygen content of waters immediately below the thermocline in the eastern basin at Stations 91, 93, and 94 offer evidence of a dissolved-oxygen minimum in this layer (Table 4). The depth of the thermocline ranged from 60 to 68 feet at these stations. These depths correspond to maximum depths at stations in the central basin where the lowest oxygen concentrations were near the bottom. It is likely that this occurrence of an oxygen minimum immediately below the thermocline represents a movement into this zone of bottom waters from the central basin. On the other hand, this minimum could have developed *in situ* due to respiration of various organisms and the oxidation of organic matter settled out from the epilimnion.

Literature Cited

AMERICAN PUBLIC HEALTH ASSOCIATION
1955. Standard methods for the examination of water, sewage, and industrial wastes. 10th ed., 522 pp.

BEETON, ALFRED M.
1961. Environmental changes in Lake Erie. Trans. Am. Fish. Soc., Vol. 90, No. 2, pp. 153-159.

BRITT, N. WILSON
1955. Stratification in western Lake Erie in summer of 1953; effects on the Hexagenia (Ephemeroptera) population. Ecology, Vol. 36, No. 2, pp. 239-244.

CARR, JOHN F.
1962. Dissolved oxygen in Lake Erie, past and present. Univ. of Mich. Inst. Sci. Tech., Great Lakes Res. Div., Publ. No. 9, pp. 1-14.

FISH, CHARLES J.
1960. Limnological survey of eastern and central Lake Erie, 1928-29. U.S. Fish and Wildlife Serv., Spec. Sci. Rept.: Fish. No. 334, 198 pp.

INTERNATIONAL JOINT COMMISSION
1951. Report of the International Joint Commission United States and Canada on the pollution of boundary waters. Washington and Ottawa, 1951, 312 pp.

MORTIMER, C. H.
1956. The oxygen content of air-saturated fresh waters, and aids in calculating percentage saturation. Mitt. int. Ver. Limnol. No. 6, 20 S.

POWERS, CHARLES F., DAVID L. JONES, PAUL C. MUNDINGER, and JOHN C. AYERS
1960. Applications of data collected along shore to conditions in Lake Erie. Univ. of Mich. Inst. Sci. Tech., Great Lakes Res. Div., Publ. No. 5 (Appendix II), 78 pp.

VAN OOSTEN, JOHN
1930. The disappearance of the Lake Erie cisco—a preliminary report Trans. Am. Fish. Soc., Vol. 60, pp. 204-214.

WRIGHT, STILLMAN
1955. Limnological survey of western Lake Erie. U.S. Fish and Wildlife Serv., Spec. Sci. Rept.: Fish. No. 139, 341 pp.

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19

Alfred M. Beeton
David C. Chandler

he St. Lawrence Great Lakes

Laurentian Great Lakes and their connect- waters constitute the largest body of fresh er on the surface of the earth (Table 19.1, . 19.1). They represent a natural resource of r-increasing importance. These lakes are vital the national economics of both Canada and United States. The fact that the lakes are nected to form a continuous waterway has n extremely important to the economy of t-central North America. Ocean vessels can w travel from the Atlantic Coast westward o Minnesota at the west end of Lake Superior, listance of almost 2,000 mi. Shipping amounts around 300 million tons per year. The Duluth-perior harbor, in western Lake Superior, ranks ond in the entire United States in the total nage handled. Traffic on the lakes has been reasing since the completion of the St. Law-nce Seaway.

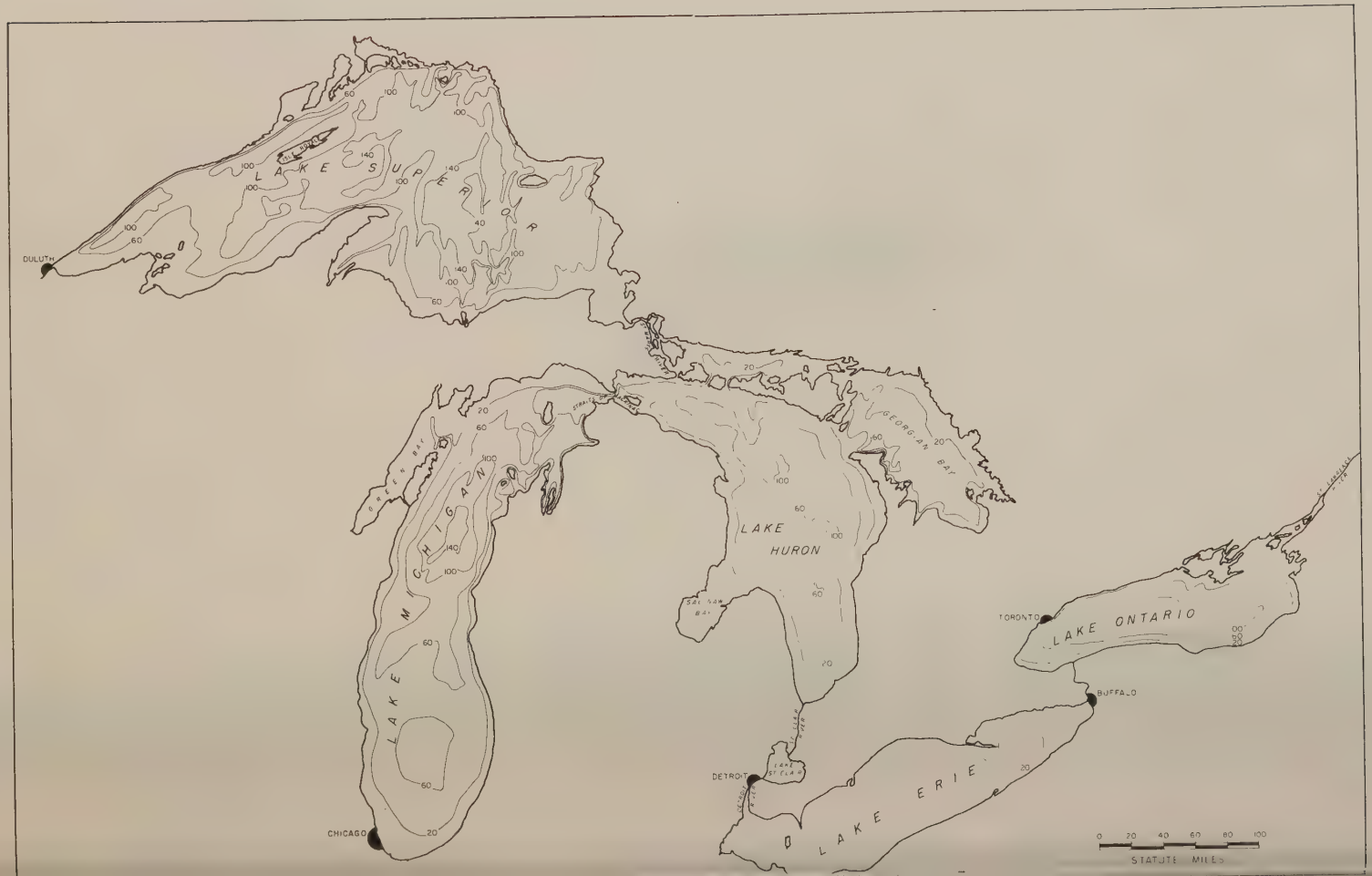
The shoreline of the lakes, including both ainland and islands, totals about 9,600 mi. ong or near the extensive coast are vast coal lds, deposits of iron, copper, and other minerals, outcrops of high-quality limestone, and areas of productive agricultural land. The lakes also temper the climate and influence the nature and movement of storm systems over an extensive area. This combination of circumstances naturally favored the development of huge industries and large metropolitan areas along the Great Lakes. Approximately 40% of the United States population lives in Great Lakes states and 10% in counties bordering the lakes. Consequently, the lake waters are used for domestic and industrial purposes, including waste disposal. Extensive commercial and sport fisheries have existed for many years, and the lakes are used for boating, bathing, and other recreation.

Human activities have affected even these large bodies of water, and there is evidence of accelerated eutrophication. The fish populations, bottom fauna, and chemical content of the waters of Lake Erie have changed markedly during the past 50 years (Beeton, 1961), and the standing crop of plankton in southern Lake Michigan has increased significantly over the past 33 years

ABLE 19.1
mensions of the Great Lakes[a]

Lake	Length (mi)	Breadth (mi)	Area: Water surface (mi²)	Area: Drainage basin (mi²)	Average surface elevation above mean sea level since 1860 (ft)	Mean discharge (cfs)	Maximum depth (ft)	Mean depth (ft)
Superior	350	160	31,820	80,000	602.20	73,300	1,333	487
Michigan	307	118	22,400	67,860	580.54	55,000	923	276
Huron	206	183	23,010	72,620	580.54	177,900	750	195
St. Clair	26	24	490	7,430	574.88	178,000	21	10
Erie	241	57	9,930	32,490	572.34	195,800	210	58
Ontario	193	53	7,520	34,800	246.03	233,900	802	283

[a] Data from U.S. Army, Corps of Engineers (1960) or personal communication.


LAKE SUPERIOR
DULUTH
LAKE MICHIGAN
GREEN BAY
CHICAGO
LAKE HURON
GEORGIAN BAY
LAKE ONTARIO
TORONTO
BUFFALO
DETROIT
LAKE ERIE
0 20 40 60 80 100
STATUTE MILES

mann, 1960). Similar changes in the other s may be as yet too limited to detect or have e undetected because we have insufficient in- nation on past conditions.

Despite the widely recognized economic impor- e of these waters, fundamental knowledge ut them is scanty. Investigations of the lakes ore 1900 were few and sketchy. From 1900 to 0 agencies concerned with commercial fish- s and water quality carried out much of the earch. Since 1950 investigations have been ex- ded to a great variety of practical and basic blems in addition to those of water quality l fisheries.

aracteristics of the Great Lakes

e large size of the lakes has limited the devel- nent of a knowledge of many aspects of their nology. Considerable information has been assed, however, on certain facets of Great kes limnology, especially those related to ap- ed limnology such as water-level records. In ner areas of interest very little is known. For mple, even a list of the more common species nprising the plankton of Lake Huron would be original contribution to the scientific litera- e. Much of the equipment and methods devel- ed for study of smaller lakes are not applicable the Great Lakes. Large vessels and sturdier uipment than those in use on small lakes are cessary. Vessels and suitable equipment have t been available, however, for extensive basic search until fairly recently. Consequently, the dependent investigator has been hampered in dertaking any large-scale studies, and much of e literature deals with limited data collected shallow areas near shore. Various ideas, as well equipment, have been borrowed from the eanographer. Bathythermographs have been in e on the lakes for many years, and Nansen ttles, reversing thermometers, Clarke-Bumpus ankton samplers, sonic fathometers, and coring vices are as commonplace on research vessels the lakes as on oceanographic vessels. The ethods used by the oceanographers are not en- rely applicable to the lakes, however, and must e modified for the conditions peculiar to these odies of water. As a consequence of the special roblems involved in studying the lakes, they ffer a common meeting ground between limnol- gy and oceanography.

Investigators have been hampered by a lack of knowledge of past conditions, although various information compiled by water treatment plants, industries, etc. for other purposes is available. Much of this information has not been published, however, and is found only in mimeographed or typewritten reports or as raw data. A total of 1,177 sources of such data are known to exist (Powers *et al.*, 1959). A study was made in Lake Erie for the U.S. Bureau of Commercial Fisheries to determine the usefulness of these observations to limnologists and fishery biologists. Total alkalinity and turbidity measurements, made by D. C. Chandler and associates at the Stone Laboratory in western Lake Erie between September 1938 and December 1945 (Chandler and Weeks, 1945) and in the central and eastern basins by personnel aboard the *Shearwater* in 1929 (Fish, 1960), were compared with data collected at water plants during the same periods. Many of the data sources are not representative of open-lake conditions because of local runoff from tributary streams which reaches the water intakes. Nevertheless, it was demonstrated that certain onshore sources are representative of conditions in the open lake, and consequently, we have an additional means for studying past and present conditions (Powers *et al.*, 1960).

The lakes individually rank among the world's greatest. Lake Superior is the largest freshwater lake of the world. It is the deepest of the Great Lakes and is the uppermost lake in the system (Table 19.1). Lake Superior discharges into Lake Huron through the St. Marys River. Lakes Huron and Michigan rank fifth and sixth in size among the world's lakes. Lake Michigan drains into Lake Huron through the Straits of Mackinac, and their surfaces have the same elevation. For some purposes the two bodies are sometimes considered as a single lake, but they differ considerably in physicochemical characteristics. Lake Huron waters discharge through the St. Clair River, Lake St. Clair, and the Detroit River into western Lake Erie. Lakes Erie and Ontario are much smaller than the other Great Lakes. Nevertheless, they rank twelfth and fourteenth among the world's largest lakes. Lake Erie discharges into Lake Ontario through the Niagara River. The waters of the Niagara make a rapid descent from Lake Erie over Niagara Falls and through the rapids above and below the falls. The difference of mean surface level between Lakes Erie and Ontario is approximately 326 ft. The St. Lawrence

River carries the discharge from Lake Ontario to the Atlantic Ocean.

The bedrock of the Great Lakes region consists of undifferentiated pre-Cambrian and sedimentary Paleozoic rocks. The basins themselves have been formed by excavation of the outcrop belts of the less resistant rocks by glacial action. Most of the basin of Lake Superior and part of Georgian Bay of Lake Huron lie in the pre-Cambrian rock of the Canadian Shield. The rest of the bedrock formation of the Great Lakes is of various Paleozoic periods. Silurian rock forms the western and northern shore of Lake Michigan, the islands and peninsula separating Georgian Bay from Lake Huron, the Niagara escarpment, and the southern shore of Lake Ontario. The Devonian shales form part of the basins of Lakes Erie, Huron, and Michigan. Ordovician shales occur along the west shore of Green Bay and in the deeper areas of Georgian Bay. Most of the Lower Peninsula of the State of Michigan is undifferentiated Pennsylvanian and Mississippian rock. Extensive glacial deposits cover most of the bedrock formations in the Great Lakes region except for the Canadian Shield (Hough, 1958).

The levels of the lakes vary within the year from an average of slightly more than 1 ft for Lakes Huron, Michigan, and Superior to almost 2 ft on Lake Ontario. The highest level occurs in the summer and the low in late winter or early spring (Corps Engr., 1960).

Wind setups and seiches have been reported for all of the lakes, and these changes in water level are very apparent on the records from the gauges maintained by the U.S. Lake Survey (Harris, 1954). Most of the literature, however, is concerned with water-level fluctuation in Lake Erie. Differences in lake-level elevations between Buffalo and Toledo have been as great as 13.5 ft (Hunt, 1958). The results of a number of studies indicate that the uninodal longitudinal seiche has a period between 14 and 15 hours. Verber (1961) has presented evidence that the actual period of this seiche depends on the elevation of the lake and the direction of the wind blowing across the long axis of the lake. The nodal line may shift over a broad nodal zone approximately 60 mi wide and may pivot according to wind direction. The basins of the lake may have independent oscillations. Consequently, the water-level records show a number of fluctuations superimposed upon each other. Methods are being developed to forecast the lake level accurately, since the f tuations are of considerable economic importa People concerned with hydroelectric power eration in the Niagara River are especially in ested in forecasting lake levels, since the ho river flow can vary from 162,000 to 330,000 in a week (Gillies, 1960).

Records of abrupt rises in water level are s tered in the literature. These waves, which h meterological origins, are referred to as sur A recent surge in Lake Michigan on 26 J 1954 took a number of lives. This surge was duced by a fast-moving squall line that pa over the southern end of the lake and may h been due to resonant coupling between a mo pressure jump line and the lake (Harris, 19 This theory did not provide an adequate expl tion of another surge, and Donn and E (1956) found that the theory of edge waves more suitable. A numerical computation met has been successfully applied to the surge of June 1954 in a study to develop a method predicting these water-level fluctuations (Pl man, 1960).

Our knowledge of the currents of the lakes increased considerably within the past few ye Nevertheless, current pattern determination mains in the early state of development. Mos the studies have been concerned with surface rents, and the nature of subsurface water m ments and their relation to the surface remai matter of conjecture. Furthermore, observat of surface currents have not extended over enough periods to support conclusions regar seasonal patterns (Johnson, 1958).

Several methods have been developed to st currents and water masses of the lakes. D missiles have been used for many years and main a satisfactory method, especially in a where the shores are highly populated. As m as 80% of the drift bottles from a single rel may be returned in a short time. Synoptic veys, i.e., the simultaneous observation of v ous limnological conditions at a number of poi have been employed by a number of agen usually on a cooperative basis. The contoured tribution of temperatures, transparency, var chemical constituents of the water such as cium, sodium, chlorides, etc., as determined these surveys, as well as direct current meas ments with dye and large floats, have been us in detecting water masses and currents.

nographers' dynamic-height method for de- ining currents has been modified for use on lakes (Ayers, 1956). It has been demon- ed that methods for making estimates of ing rates, seaward transport of river water, exchange of sea and river water in marine aries can be used to evaluate the circulation Saginaw Bay (Beeton and Hooper, 1961). A hod for estimating the rate of littoral trans- has been developed. An equation was de- d relating transport rate to wave energy (Ba- nas, 1960).

nportant direct factors in the production of non- odic horizontal currents in ... [the] Great Lakes ear to be the wind, rotation of the earth, the sev- effects of the lake basins which confine the lakes, the flow-through of water supplied by runoff, nd-water seepage, and precipitation onto the s. As yet it is impossible to assess the relative ue of all these factors, but at this time it appears cal to consider that the wind is the primary energy the movement of water and the establishment of izontal current patterns. The rotation of the earth difies the direction in which wind energy is effec- e. The basins influence currents by modifying id at the shores, by interposing physical barriers, well as by bottom friction [Ayers *et al.*, 1958].

Present evidence indicates that the currents in st of the lakes are variable and respond rather ickly to wind changes. Synoptic surveys of kes Huron and Michigan indicate that some ge eddies develop in these lakes and that the w-through in Lake Huron and the outflow of ke Michigan lend some stability to the current tterns (Ayers *et al.*, 1956, 1958). Johnson 958) found no one characteristic current sys- m in Lake Huron, although a general but highly riable west-to-east drift was usually present. rface currents were highly variable in all areas Lake Michigan, and a stable pattern was not tected during 1954 or 1955. A north-bound rrent was observed, however, along the eastern ore several times (Johnson, 1960).

An attempt has not been made to study the neral circulation in all areas of Lake Superior. he published (Ruschmeyer *et al.*, 1958; Beeton *al.*, 1959) and unpublished data show, how- er, that certain persistent currents occur. A ell-defined littoral current flows from west to st along the south shore. This littoral current ay be part of a general counterclockwise circu- tion of the entire lake.

All of the lakes exhibit some degree of thermal ratification during the warmer months. They probably mix deeply throughout most of the winter and spring, since solid ice sheets are mostly limited to such sheltered areas as embay- ments, channels, among islands, and along shore. Ice in the main lakes usually occurs as floes. The smaller lakes, Erie and Ontario, may have 80 to 95% of their surfaces ice-covered in severe win- ters. The ice cover also can extend large dis- tances from shore in Lake Superior during an unusually cold winter. Lakes Huron and Michi- gan normally remain open, although shore ice may extend 8–10 mi out into the lakes. The effect of deep mixing is apparent in Lake Superior where homoiothermous water around 2°C occurs to depths of 600 ft (Beeton *et al.*, 1959). The lakes differ chiefly in the rate at which they warm and in the stability of the thermal stratifi- cation. The deep waters of all the lakes probably remain close to 4° C throughout the year. Well- defined and persistent thermal stratification is usually established in Lake Erie by mid-June and in Lakes Huron, Michigan, and Ontario by the end of June. The epilimnion extends to about 45 ft in Lakes Huron, Michigan, and Ontario and to 65 ft in Lake Erie during the period of maximum stratification in August. Lake Superior, which is much colder than the other lakes, usually does not exhibit any well-defined stratification until mid-July. The lower limit of the epilimnion is around 45 ft. Thermal stratification is not uni- form from area to area, and the metalimnion is usually poorly developed.

The Great Lakes consist of bicarbonate waters. Total alkalinity ranges from 46 ppm (as $CaCO_3$) in Lake Superior to 113 ppm in Lake Michigan (Table 19.2). The *p*H ranges from 8.0 to 8.5 for most of the waters, except Lake Superior. Sul- fate concentrations are greater than chlorides in the upper lakes, and they are almost equal in Lakes Erie and Ontario. The proportions of cal- cium, magnesium, and sodium in the upper lakes are about 10:3:1. Potassium usually averages around 1 ppm in all the lakes. Silica usually fluc- tuates around 2–3 ppm, although only trace amounts of silica occur at times in the highly productive waters of Lake Erie. Concentrations of total phosphorus are low in the upper lakes and are usually less than 5 ppb in the open wa- ters of Lake Superior. The phosphorus content of water from Lake Erie is about six times greater than that in the other lakes. The dissolved-oxy- gen content of most of the lake waters is near

TABLE 19.2

Average chemical characteristics of Great Lakes waters. U.S. Bureau of Commercial Fisheries data, unless d nated otherwise. Data based on samples from various depths.

Lake	Calcium (ppm)	Mag-nesium (ppm)	Potas-sium (ppm)	Sodium (ppm)	Total alkalin-ity (ppm $CaCO_3$)	Chloride (ppm)	Sulfate (ppm)	Silica (ppm)	Total phos-phorus (ppb)	*p*H	Specif conduct (microm at 18°
Superior	12.4	2.8	0.6	1.1	46	1.9	3.2	2.1	5	7.4	78.7
Huron	22.6	6.3[a]	1.0	2.3	82	7.0	9.7	2.3	10	8.1	168.3
Michigan	31.5	10.4	0.9	3.4	113	6.2	15.5	3.1	13	8.0	225.8
Erie	36.7	8.9	1.4	8.7	95	21.0	21.1	1.5	61	8.3	241.8
Ontario	39.3	9.1[b]	1.2	10.8	93[c]	23.5	32.4	0.3	—	8.5[c]	272.3

[a] Ayers *et al.*, 1956.
[b] Leverin, 1947 (average from Toronto intake).
[c] New York State Dept. Health, 1958.

saturation, even at the greatest depths, and supersaturation is common. Dissolved-oxygen concentrations of less than 1 ppm have been found in Lake Erie. These low values have been detected in the bottom waters in an area of several hundred square miles of the central basin.

The Great Lakes plankton is characteristic of large and deep lakes. Diatoms are the most important constituents of the plankton, although zooplankton may occasionally equal the diatoms in biomass but not in numbers. Blue-green and green algae are especially abundant at times in Lake Erie and probably in Lake Ontario. Even in Lake Erie, however, diatoms usually comprise 75% of the phytoplankton. The more abundant diatom genera are *Asterionella, Cyclotella, Fragilaria, Melosira, Synedra,* and *Tabellaria.* Copepods make up the bulk of the zooplankton, although protozoans are more numerous. Cladocerans are very abundant in the summer, and rotifers, especially *Keratella,* are usually plentiful. *Cyclops bicuspidatus, Diaptomus minutus, D. sicilis, D. ashlandi,* and *D. oregonensis* are especially plentiful in Lake Erie and in the upper strata of the other lakes. The cold-water copepods *Limnocalanus macrurus* and *Senecella calanoides* are taken in the deep waters.

Little is known of the abundance of plankton in the lakes. Nothing has been published on Lake Huron plankton, and only a few studies have been made on the other lakes. Most of the work has been on Lake Erie. The studies that have been made indicate two periods of peak plankton abundance in spring and fall (Ahlstrom, 1936; Beeton *et al.,* 1959; Chandler and Weeks, 1945; Davis, 1954; Fish, 1960; Wright, 1955).

The spring pulse consists almost entirely diatoms. Populations of blue-green and gr algae build up during August and September contribute to the fall pulse, although diatoms still dominant. These phytoplankton pulses very important in the productivity of lakes. Phytoplankton populations existing tween pulses in Lake Erie in 1942 made up 17% of the annual crop (Chandler and We 1945). Large zooplankters of Lake Erie are ab dant in summer and the smaller ones in spr and fall (Davis, 1954). Most of the Crustacea Lake Michigan reach only one population pea year. Cladocerans and the copepods *Mesocycl edax* and *Epischura lacustris* probably overwi as eggs (Wells, 1960). *Cyclops bicuspida* which is a winter and early spring form in L Erie (Andrews, 1953), is apparently plent throughout the entire year in the colder envi ment of Lake Michigan (Wells, 1960). Furt generalization on plankton abundance would meaningless, since special sampling problems h not been resolved, and most of the studies h been limited to observations during only part the year. Sampling at a given station present problem, since different water masses are pr ably sampled on each visit (Davis, 1954). Y round studies over four years in Lake showed that each year the quality and quan of the phytoplankton were different. Co quently, Chandler and Weeks (1945) conclu that "until a greater knowledge of the extent the annual variations is acquired any attemp generalize on the basis of observations limited one season or even a complete year will h little meaning."

ıe results of the limnological surveys con- ed in Lake Erie in 1928 and 1929 remain the source for information on the horizontal dis- ıtion of plankton. Considerable variation ed in both the quality and quantity of plank- in different areas of the lake and at different s (Fish, 1960). The vertical distribution of t species of cladocerans, nine species of cope- s, and the two benthic malacostracans, *Pon- reia affinis* and *Mysis relicta*, was studied in e Michigan (Wells, 1960). All species mi- ed toward and attained their greatest num- at the surface late in the day, apparently in onse to diurnal changes in light intensity. number of individuals at the surface de- sed toward midnight, and limited evidence cated an increase for some species at the sur- again slightly before dawn. A more detailed dy of the migratory behavior of *M. relicta* cated that light "triggers" and controls their rations, while thermal conditions interact with modify the influence of light (Beeton, 1960). the length of day decreased following the ımer solstice, the mysids ascended progressively lier each evening and descended later each rning. Moonlight and fog influenced the time well as the amplitude of the vertical migra- n. The mysids frequently migrated through metalimnion when first ascending, but later the night the majority occurred in or immed- ely below this layer.

Attempts to obtain estimates of the produc- ity of Great Lakes phytoplankton populations ve met with certain problems not confronting nologists working on most smaller lakes. The v plankton populations in Lake Superior made necessary to use artificially concentrated sam- s for productivity measurements. Even a five- d concentration was not sufficient, however, for asurement of photosynthesis by the light and rk bottle oxygen technique in Lake Superior utnam and Olson, 1961). Estimates of produc- ity made at a few stations are obviously not presentative of conditions in an entire lake or en in the larger bays. Consequently, studies being made to develop methods that would applicable to large lakes (Bachmann *et al.*, 61). Most of the work on productivity has en carried out in western Lake Erie. Methods determining photosynthetic and respiratory es by measuring *p*H differences have been veloped for use in dark and light bottle ex- periments (Verduin, 1956) and under com- pletely natural conditions (Verduin, 1960). Changes in *p*H are converted to CO_2 change by referring to a differential titration curve. Recent studies employing these methods indicate that when natural population densities are used, the photosynthetic yield (average 1.6 micromoles of CO_2 absorbed per microliter of plant volume per hour) is three times higher than previously re- ported yields from experiments using artificially concentrated populations. Furthermore, measure- ments of photosynthetic activity under com- pletely natural conditions result in values sig- nificantly higher than those from photosynthesis in bottles (Verduin, 1960).

The deep-water bottom fauna of the Great Lakes is dominated by the amphipod *P. affinis* and the opossum shrimp (*M. relicta*). Oligo- chaetes, especially *Limnodrilus*, and the Sphae- riidae, *Pisidium* and *Sphaerium*, are also numerous. Midge larvae of the genus *Spaniotoma* are found at depths greater than 30 fathoms. The shallow- water fauna has many of the species common in the smaller inland lakes. Hirudinea and various tendipedids are plentiful at depths less than 40 fathoms. Various gastropods—*Lymnea, Valvata, Amnicola, Goniobasis*—are important in shallow areas. Trichoptera larvae and especially the ephemeropteran, *Hexagenia*, are abundant in some areas.

Hexagenia nymphs dominated the benthos of western Lake Erie prior to 1953. Data pub- lished by various investigators indicate that the population averaged around 400 nymphs per m^2. A severe reduction in dissolved oxygen in the bottom waters, associated with unusual thermal stratification of the western basin, killed a large percentage of the mayflies (Britt, 1955). Subse- quent studies indicate that the mayfly popula- tion has remained at about 10% of its former abundance, and substantial increases have oc- curred in the population of oligochaetes and midge larvae (Beeton, 1961). These changes in the benthos certainly are not due to the one period of low dissolved-oxygen concentrations, and shifts in the fish populations and increases in the chemical content of the water indicate a changing environment.

An average of approximately 1,200 benthic animals per m^2 has been reported for Lake Huron (Teter, 1960) and Lake Michigan (Eggle- ton, 1937). The greatest concentration of organ-

isms, 11,440 animals per m^2, was found in Lake Michigan, although a maximum of 10,556 occurred in Lake Huron. Seasonal changes in abundance of organisms and a zone of maximum abundance at about 140 ft, noted by Eggleton in Lake Michigan, were not found in Lake Huron (Teter, 1960) or during a more recent study of Lake Michigan (Merna, 1960).

The fish fauna of the Great Lakes and tributaries includes representatives of most families of North American fishes. Salmonid fishes dominated the early fisheries of all the lakes. In Lake Superior no other group has produced any substantial amounts. The lake trout (*Salvelinus namaycush*) and the coregonids (whitefish, lake herring, chubs) have been the most important commercial species in the upper lakes. Certain shallow-water areas, bays, and the lower lakes have yielded large quantities of Percidae, Catostomidae, and Ictaluridae. Yellow perch (*Perca flavescens*), the pike-perches (*Stizostedion* spp.), white bass (*Roccus chrysops*), and the freshwater drum (*Aplodinotus grunniens*) are abundant in Lake Erie. Native species include vast numbers of small fishes—various cyprinids, cottids, sticklebacks, trout-perch—that do not enter into the commercial catch, but some have value as bait fish. The fish fauna has been modified greatly by the introduction and immigration of exotic species. Carp were introduced the latter part of the 19th century, and substantial populations were well established by 1900. Smelt (*Osmerus mordax*) were stocked in a lake tributary to Lake Michigan in the 1920's. In a relatively short time they spread throughout the upper Great Lakes and into Lake Erie. They are native to Lake Ontario. The sea lamprey (*Petromyzon marinus*) and the alewife (*Alosa pseudoharengus*), now abundant in most of the lakes, were unknown except in Lake Ontario prior to the opening of the Welland Canal. Carp and smelt have contributed substantially to the commercial take. Alewife, despite its abundance, has proved difficult to market. The white perch (*Roccus americanus*) is a recent immigrant. A large population is established in Lake Ontario in the Bay of Quinte, and a number have recently been captured in eastern Lake Erie (Scott and Christie, 1961). Several pink salmon (*Oncorhynchus gorbuscha*) have been caught in Lake Superior in recent years. Apparently a number of these fish escaped from a hatchery, and a small population has been established that spawned successfully (Schumacher and E 1960). The relationship of these exotics to o species is as yet unknown, except for the lamprey which has resulted in drastic decre in the abundance of certain of our native fis

History of limnological research on the la

The development of an extensive scientific erature concerning the lakes within recent y has been phenomenal. Less than 100 years most of the lakes region was yet a wildern and only limited general information about Great Lakes was available. The Great L bibliography compiled by John Van Ooster 1957, however, has almost 3,000 entries, there are several thousand additional referen a good proportion from recent years.

The discussion of research on the lakes been divided into 3 sections: pre-1900, *c* 1900–1949, and *circa* 1950 to present. The parent development of a different approach research on the lakes around 1900 and greatly increased tempo of research since al 1950 make these periods meaningful in the tory of Great Lakes limnology.

Pre-1900

Professor Louis Agassiz and 15 fellow sc tists and students embarked from Sault Marie on 30 June 1848 in one large Macki boat and two canoes on what was probably first purely scientific expedition on the G Lakes (Agassiz, 1850). Their objective wa study the natural history of the north shor Lake Superior. The observations made by group stand as one of the best sources for formation on this region while it was ye wilderness. This expedition contributed littl our knowledge of the limnology of the la although some observations were made of face water temperatures, transparency, and wa level fluctuations. The discussions of the fi of Lake Superior by Agassiz and of Coleop by Leconte, however, are especially valuabl

It is not to be implied that Agassiz's exp tion is the start of scientific interest in Great Lakes. Considerable knowledge had accumulated on mineral deposits, and the G Lakes were already important for shipping 1848. The importance of shipping undoubt generated considerable interest in water-l

tuations, since channels had not been dredged in important waterways such as the St. Clair er delta where depths of only 7 to 10 ft ted in the channel. Father Marquette in 3, Father Louis Hennepin in 1679, Baron nton in 1689, Charlevoix in 1721, as well as umber of military men in the early 1800's had erved short-term changes in the water level Lake Michigan and had expressed the opinion t these fluctuations were produced chiefly by winds (Dearborn, 1829). Considerable spec- tion arose that these fluctuations were tides, l Graham (1861) and Comstock (1872) pre- ted evidence for a small tide in Lake Michi- n of about 0.14 to 0.20 ft. Most of the changes water level were shown to be seiches (Per- s, 1893; Henry, 1900), although there are a mber of records of very abrupt and large anges in water level in the lakes which were led tidal waves by some investigators.

Interest in the physicochemical characteristics the Great Lakes, other than water-level fluc- ations, developed slowly. A few measurements surface temperatures of Lake Ontario were ade in 1838 (Dewey, 1838), but 50 more years ssed before much was known of subsurface mperatures (Drummond, 1890). The U.S. Lake rvey had established water-level gauges at a mber of harbors on the lakes prior to 1860 d conducted a number of surveys, so that by 87 data on lake and watershed areas, mean d maximum depths, and elevation of lake rfaces above mean sea level had been com- led (Schermerhorn, 1887). Concern over sew- e disposal and location of water intakes stim- lated some early interest in lake currents Clark, 1892). The major study of currents, owever, was that made during 1892–94 by the .S. Weather Bureau (Harrington, 1895). It is nly recently that more detailed studies have een made, and Harrington's surface-current harts are still a reference source (Hough, 1958). robably the best information on early chemical nalyses of the lake waters is Lane's paper 1899), which includes data from as early as 854.

Early work on plankton was usually related to vater supply or fisheries. These studies were axonomic or distributional, except for the quan- itative sampling by Reighard (1893). Kellicott 1878), Mills (1882), and Vorce (1882) studied he microscopic life in the Lake Erie water sup- plies of Buffalo, N.Y., and Cleveland, Ohio. The earliest paper on Lake Michigan plankton is that of Briggs (1872), although Thomas and Chase (1887) had initiated their study of diatoms in the Chicago water supply in 1870. Birge's (1881) paper on Cladocera was based on samples from the Chicago water supply. Most of the studies made by Forbes (1891) were related to fishery problems.

Dredging for deep-water fauna in Lake Michigan was initiated by the Chicago Academy of Science in 1870. The collection of the crustaceans, *Mysis relicta* and *Pontoporeia affinis*, which have close marine affinities, off Racine, Wisconsin, in 1870 led to speculation that the bottom of Lake Michigan might be brackish (Hoy, 1872). The U.S. Army, Corps of Engineers, conducted extensive sounding and dredging in Lake Superior in 1871. The reports prepared by Sidney I. Smith (1874) remain as our only source of published data on the deep-water benthos of the open waters of Lake Superior. The first study of the Lake Ontario benthos was being conducted by Nicholson (1872) at this time.

The U.S. Commission of Fish and Fisheries survey of the fishery resources, initiated in 1871 (Milner, 1874), marked the beginning of the U.S. Government's interest in the Great Lakes fisheries. At that time the fishing industry on Lake Michigan alone employed about 2,000 men and operated about 600 fishing vessels. An estimated 32.2 million pounds of Great Lakes fish were handled by the major markets annually, but many additional pounds were undoubtedly consumed locally. Milner's tour of the shore and islands of Lake Michigan permitted him to compile considerable information on the life histories of the fishes. The revenue vessel *Johnson* was used for dredging and trawling on a two-week cruise in September 1871. Unfortunately Milner's collection of fish and invertebrates, stored at the Chicago Academy of Science, was destroyed in the great Chicago fire of 1871. Milner extended his survey to Lakes Superior, Huron, St. Clair, and Erie in 1872. His report mentions what was probably the first attempt to study fish migration in the lakes by tagging whitefish with a small metal tag.

Increasing public concern over the decline of the fisheries of the lakes, especially in the contiguous waters of Canada and the United States, led to the establishment of federal and state

fishery agencies. The Michigan Board of Fish Commissioners, established in 1873, demonstrated great interest in the Great Lakes fisheries (Jerome, 1879). Recognition of the need for cooperation in preserving the lake fisheries led to a number of informal international conferences in the late 1870's. A Joint Commission was appointed by the United States and Great Britain in 1893 (Rathbun and Wakeham, 1897). Evidence of a decline in the fisheries had been offered as early as 1871 (Milner, 1874). Undoubtedly Milner's recommendations for artificial propagation of fish and protective legislation to reverse the decline in the abundance of fish guided future fishery work for many years on the lakes. By 1874 the Michigan Board of Fish Commissioners had established a hatchery on the Detroit River. The U.S. Government acquired the hatchery at Northville, Michigan, in 1880, primarily for the propagation of whitefish. A small station, to serve as a supplier to the Northville hatchery, was established at Alpena, Michigan, in 1882. By 1888 the U.S. Government was operating a hatchery owned by the state of Ohio at Sandusky, Ohio, and had started construction of a hatchery at Duluth, Minnesota. Additional hatcheries were established at Put-in-Bay, Ohio, and Cape Vincent, New York, in 1890 and 1896. Several of the lake states established hatcheries during this period, and the Canadians had operated a hatchery at Newcastle, Ontario, for about 20 years before establishment of the first U.S. Government station on the lakes.

The only additional fishery work of consequence during this period is the surveys, conducted by the U.S. Commission of Fish and Fisheries, of the history, apparatus, methods, and statistics of the fisheries in 1885 and 1892 (H. M. Smith, 1894).

1900–1949

Commercial fishing had become increasingly important during the latter part of the 1800's, but concern existed over declining fish populations, especially whitefish, and dissatisfaction developed over the methods being used to reverse this decline—restrictive legislation and the fish hatchery operations. Reighard's (1899) answer to this problem marked a new approach to study of the lakes: "Is it not better . . . to take up the study of the biology of the lakes from the point of view of pure science for the purpose of finding out as far as possible of the facts and making clear as many as possible of the principle Then when, in the future, any fisheries proble arise, the facts and principles for their soluti will have been already determined in large par This concept was the basis for the biologi investigations that Reighard undertook on La St. Clair in 1893 for the Michigan Fish Comm sion (Reighard, 1894) and on Lake Erie 1898–1902 for the U.S. Commission of Fi (U.S. Comm. Fish, 1900). The studies ma of Lake Michigan in 1894, under the direction H. B. Ward for the Michigan Fish Commissi (Ward, 1896), were a continuation of the search initiated on Lake St. Clair. Some of o country's foremost biologists were associat with these studies. The results of work conduct by E. A. Birge, C. A. Kofoid, Frank Smi H. D. Thompson, Bryant Walker, R. H. W cott, and W. McM. Woodworth were publish as appendices to papers by Reighard (1894) a Ward (1896). Papers by Jennings (1904) on t rotifers, Marsh (1895) on the copepods, Piet (1894) and Snow (1904) on higher plants a algae, and Moore (1906) on Hirudinea a Oligochaeta were published separately.

The general concern generated by the collap of the Lake Erie cisco fishery in 1925 resulted two extensive limnological surveys. The produ tion of this fishery had averaged about 20 m lion pounds annually, but it dropped to 5.5 m lion in 1925 and to 1.9 million in 1928 (V Oosten, 1930). The state of Ohio undertook survey in 1926, under the direction of Raymo Osburn, to determine the extent of pollution a its influence on the fish. The U.S. Bureau Fisheries, also concerned over the loss of t cisco fishery, established the Great Lakes Fishe Investigations under the direction of John V Oosten in 1927 (the U.S. Government h financed the researches of Walter Koelz [192 on the taxonomy of the coregonids and of V Oosten [1929] on the life histories of the la herring and whitefish prior to this time), h the 1927 action was the beginning of a continui federal fishery program on the lakes (Hile, 195 The Bureau of Fisheries cooperated with t state of Ohio in the study of western Lake E in 1927. The program was expanded greatly 1928 to cover the entire lake. The survey of t western basin continued under the auspices the state of Ohio, although Stillman Wrig U.S. Bureau of Fisheries, directed the field wo in limnology. Studies were made of the physi

iology, chemistry, plankton, and benthos ight, 1955). The Province of Ontario, Buf- Museum of Science, New York Conserva- Commission, Buffalo Health Department, and U.S. Bureau of Fisheries cooperated in the ey of eastern and central Lake Erie during 8–29. The Bureau of Fisheries assigned its oot vessel, the *Shearwater* (previously as- ed to the Put-in-Bay Hatchery), to this sur- . This vessel was probably the first sizeable ery research vessel on the lakes. The scope the limnological survey of the eastern and tral basins was similar to that of the survey the west end, although the benthos was not uded (Fish, 1960). Some additional informa- n on this survey, especially on the fish, was luded in an earlier report (New York Conserv. pt., 1929).

The third major fishery-limnological survey s carried out from the 102-foot research vessel *Ilmar* by the Bureau of Fisheries in Lake chigan in 1930–32. The states of Michigan l Wisconsin and four net manufacturers con- buted financially to this investigation of the l net mesh size that would allow the most cient capture of chubs with the least destruc- n of small lake trout. Extensive limnological ta were collected, and papers have been pub- hed on the plankton (Ahlstrom, 1936), benthos ggleton, 1937), surface currents (Deason, 1932; n Oosten, 1962), and temperatures (Van Oos- n, 1960). This survey marked the end of any tensive field work on the lakes by the U.S. ureau of Fisheries for the next 15 years, 1933– (Hile, 1957).

Much of the work at the Franz Theodore one Laboratory, Ohio State University, has en related to fishery problems. David S. Kelli- tt, who promoted the establishment of the ake Laboratory in the State Fish Hatchery at ndusky, Ohio, in 1896, recognized the need for udies of biological problems related to fisheries. wo of the laboratory directors, Raymond Os- rn and T. H. Langlois, were closely associated ith the Ohio Division of Conservation. The boratory was moved from Sandusky to Cedar oint in 1903, transferred to the State Fish atchery at Put-in-Bay in 1918, and relocated its present site on Gibraltar Island in 1925.

Starting in 1938 the laboratory was operated ll-time under the direction of Langlois and a search staff consisting of David C. Chandler, I. B. Trautman, and Charles F. Walker. Year-round studies, which led to the development of special equipment and methods for working through the ice, were conducted for ten years. The research program was concerned with the general ecology of western Lake Erie, including the terrestrial as well as the aquatic environment and the relationship of man to this environment. The philosophy back of this research program was that changes in the biota, especially in fish populations, were the result of environmental changes. Furthermore, these environmental changes were due to allochthonous as well as autochthonous processes which could be measured. A very broad program was undertaken to study conditions in the lake as well as on the watershed. Extensive meteorological data were collected for many years. Studies made by the staff, numerous graduate students, and visiting investigators added substantially to our knowledge of the life histories and ecology of fishes and numerous invertebrates. The circulation of western Lake Erie was naturally of interest to the various investigators, and several studies were made of currents. Individual water masses with their characteristic biota and physicochemical conditions were recognized. The plankton of Lake Erie is better known than in the other lakes primarily because of the work of L. H. Tiffany, C. E. Taft, and D. C. Chandler during this period. Detailed references to these studies are given in the summary by Langlois (1949).

The year-around program was discontinued in 1955; nevertheless, limnological research and teaching have been maintained during the summers by Jacob Verduin and N. Wilson Britt. Most of the present research has been directed towards problems related to the productivity of Lake Erie (Verduin, 1960).

Canadian fishery and limnological studies on the lakes were conducted by the Biological Board of Canada, the Ontario Fisheries Research Laboratory of the University of Toronto, and the Fisheries Research Laboratory of the University of Western Ontario. The Biological Board maintained the Georgian Bay Biological Station from 1901 to 1914. Results of most of the work at the station were published in a single volume and included, among others, papers by B. A. Bensley on fishes, G. O. Sars on Entomostraca, E. M. Walker on Odonata, and Wilbert A. Clemens on Ephemeridae (Prince, 1915). Several papers on Great Lakes fishes originated from the Ontario Fisheries Research Laboratory dur-

ing the 1920's. The Fisheries Research Laboratory, at Erieau, Ontario, conducted limnological sampling in Lake Erie, primarily during the summers, in 1947–53. These data are included in a report by Powers *et al.* (1960).

An International Board of Inquiry for the Great Lakes Fisheries was established by Canada and the United States in 1940. A four-member board consisting of Hubert R. Gallagher (Council of State Governments), A. G. Huntsman (Fisheries Research Board of Canada), D. J. Taylor (Ontario Game and Fisheries Department), and John Van Oosten (U.S. Fish and Wildlife Service) was appointed to make a study of the fisheries and to make recommendations for preserving and developing the fisheries of the lakes (Intern. Board Inquiry, 1943). This inquiry included a historical review of the various international and interstate conferences on Great Lakes fisheries, detailed production statistics of the commercial fisheries, and recommendations for preserving the fisheries. A treaty was negotiated between the United States and Canada for international investigation and control of the lake fisheries. It was never ratified, however, and this attempt to obtain uniform regulation of the fisheries failed.

Concern over the decline in the quality of Great Lakes waters also resulted in several major surveys and a number of smaller investigations after 1900. The Lake Michigan Water Commission, established in 1907 by the states of Illinois, Indiana, Michigan, and Wisconsin, and several municipalities, made a number of studies of water chemistry, plankton, and currents between 1907 and 1911 (Lake Michigan Water Comm., 1911). During 1906–07 the U.S. Geological Survey carried out its investigation of the chemical content of Great Lakes water (Dole, 1909). The Boundary Waters Treaty of 1909 between Canada and the United States provided for the establishment of the International Joint Commission to investigate the pollution of boundary waters. The first of two major surveys made by this commission (in 1913) concerned coliform bacteria in the St. Marys River, the St. Clair-Detroit River and western end of Lake Erie, eastern Lake Erie and the Niagara River, and Lake Ontario and the St. Lawrence River. A larger study, including water chemistry, bacteria, and currents, was made in these same areas in 1946–48 (Intern. Joint Comm., 1951).

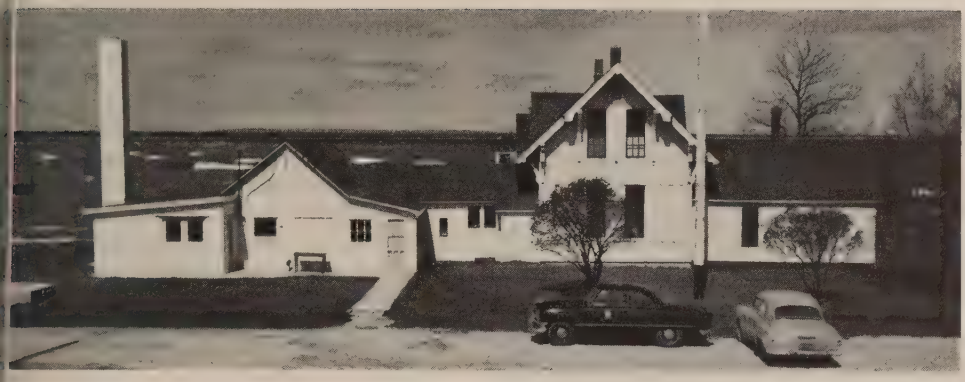
The U.S. Public Health Service made an vestigation of pollution in southern Lake Mi gan in 1924–25 (Crohurst and Veldee, 192 The surveys of water quality in Saginaw B Lake Huron, by the Michigan Stream Con Commission in 1935–36 resulted in the first p lished record of the use of the "synoptic surv approach on the Great Lakes. The literature c tains only scattered references to this stu although it is one of the most extensive surv carried out on the lakes. This large bay sampled about once a week, and the survey v sel traveled approximately 7,000 mi during 15-month study (Adams, 1937). Surveys w made of pollution in southern Green Bay 1938–39 (Williamson and Greenbank, 1939) of the Ohio waters of Lake Erie in 1950 (Ohio Dept. Nat. Resources, 1953). The m recent survey is that of Lake Ontario in 1 (New York State Dept. Health, 1958).

Numerous other smaller studies related to wa quality and waste disposal have been made on lakes, but many of these were conducted municipalities, industry, and engineering firms have not been published. Among those that h been published for Lake Erie are the studies pollution and currents by Fell (1910), and plankton by Davis (1955) and Gottschall Jennings (1933). The important work on hydrology of the Great Lakes by Horton Grunsky (1927) was undertaken because of wa quality and pollution problems in southern L Michigan.

Several limnological investigations were m that were not especially related to fisheries water quality. Among those concerned with ph ical limnology are Hayford's (1922) work seiches, and the studies of lake temperatures Millar (1952) and Hachey (1952). Chur (1942, 1945) investigation of the thermal cy of Lake Michigan remains as our best source information. The monumental work of Leve and Taylor (1915) on the geology of the G Lakes was completed during this period. Sev publications appeared on plankton (Eddy, 19 and benthos (Goodrich and van der Scha 1932).

1950 to present

The past twelve years have seen a substan increase of interest in the Great Lakes and in capability of a number of groups to cond



19.2.—Hammond Bay Laboratory, U.S. Bureau Commercial Fisheries.

earch on the lakes. These developments prob-y arose indirectly from man's greater concern r his environment and the possibility of con-lling it, although serious changes in the lake heries, increased use of the lakes for water pply and waste disposal, shore-erosion problems, l the building of the St. Lawrence Seaway ve generated heightened regional interest in the es.

Much of the recent work has been conducted governmental and university agencies that have oad interests in the Great Lakes. Consequently, eir research programs are discussed in some tail. Still other agencies have research programs ncerned with particular aspects of the Great kes environment. Eighteen agencies presented orts at the Third Conference on Great Lakes search in Ann Arbor in 1959. Much of their search is highly specialized, limited to certain cets of the environment, or associated with the oader programs of other agencies. These pro-ams are described in less detail.

U.S. Bureau of Commercial Fisheries.—Fishery search on the lakes has laid special emphasis control of the sea lamprey (*Petromyzon arinus*) since 1949. Sea lampreys were found ove Niagara Falls in 1921, and they had mi-ated into Lake Huron by the early 1930's. ologists had warned of the potential menace the lamprey in the upper Great Lakes, but bstantial funds for sea lamprey research were t allocated by the Congress of the United States til 1950. By that time the lake trout fishery d disappeared in the U.S. waters of Lake uron, trout production had fallen by 95% in ke Michigan, and lampreys had entered Lake Superior (Applegate and Moffett, 1955). Fishes other than the lake trout have been affected by the lamprey. Whitefish and suckers have been the principal prey in shallower waters, although the walleye population of Saginaw Bay has been greatly reduced. In deeper waters populations of the larger chubs (*Coregonus* spp.) have suffered devastating inroads (Moffett, 1957).

The substantial allotment of funds in 1950 to the Great Lakes Fishery Investigations of the U.S. Fish and Wildlife Service (now the Ann Arbor Biological Laboratory, U.S. Bureau of Commercial Fisheries) made it possible for the first time for this agency to organize a comprehensive research program. In consideration of the burden involved in establishing and administering this greatly expanded program, Van Oosten was relieved of administrative duties to devote full time to the completion of his numerous researches in progress. James W. Moffett was appointed the new Chief of the Great Lakes Fishery Investigations. Ralph Hile has been Assistant Chief of the Investigations until a recent reorganization, whereby Leo Erkkila was appointed Assistant Director in charge of sea lamprey research and control, and Paul Eschmeyer was appointed Assistant Director of biological research. Ralph Hile has remained on the staff as a Senior Scientist.

Headquarters for the expanded program continued to be in Ann Arbor, Michigan. Field stations were established in 1950 at Hammond Bay (near Rogers City, Michigan, Fig. 19.2), Marquette, Michigan, and Sturgeon Bay, Wisconsin, and in 1956 at Ludington, Michigan. The Sturgeon Bay station was closed in 1953. A station was maintained at Oconto, Wisconsin, for a short time.

Fig. 19.3.—Type of electrical barrier used for control of sea lamprey.

The sea lamprey program was organized along two major lines: development of control procedures; testing of those procedures in a practical field program of experimental control.

Research was undertaken almost immediately to develop electrical barriers, since blocking weirs and other mechanical barriers to prevent the upstream spawning migration of the sea lamprey were found to be unsatisfactory. Although many improvements and refinements were made subsequently, effective electrical barriers, powered by 110-volt a–c current, were devised and turned over to the experimental control group in 1951. Several pilot models were tested in 1952, and ten barriers were in operation in Lake Superior tributaries in 1953 (Fig. 19.3). Barriers were installed in all of the important spawning streams along the U.S. shore of the lake, and considerable numbers were installed in the tributaries of northern Lake Michigan.

The staff of the Hammond Bay Laboratory was assigned next to a search for a selective toxicant that would kill sea lamprey ammoc without damaging other fish and organisms. T highly speculative undertaking involved thousa of bioassays that covered more than 4,000 che cals. Several effective compounds were discove one of which (3-trifluormethyl-4-nitrophenol being used in the present chemical control gram. All Lake Superior tributaries contair larval lampreys have been treated by biolog of the bureau and the Fisheries Research Bo of Canada, and a start has been made on stre of northern Lake Michigan and Georgian of Lake Huron.

The sea lamprey program is a fine exam first of federal-state and later of internati cooperation. All of the states affected by lamprey depredations have supported the U Government's program wholeheartedly. Michi and Wisconsin assigned personnel to control o ations and to a variety of special resea projects.

The Bureau of Commercial Fisheries has de oped a substantial fishery-limnological resea program separate from the sea lamprey progr This research is intended to give the broad continuing coverage that leads to basic un standing of fish stocks—the relations of spe to each other, factors of fluctuations in gro and abundance, and the effects of the envi ment and of varying rates of exploitation. Ma problems being studied at present are the re bilitation of the lake trout populations, trem dous fluctuations in the abundance of cer fishes, and the effect on fish populations o changing environment. Field stations have b established at Ashland, Wisconsin, and Sandus Ohio. The old fish hatchery at Northville, Mi gan, is presently being used to rear coregon for taxonomic studies including morpholog differences and chromosomal and serological dence on relations among species.

Three research vessels are assigned to fish limnological research. The 65-foot *Cisco* (launc in 1951) was the first vessel especially desig for investigations on the Great Lakes (Fig. 19 The *Siscowet,* a 55-foot gill net tug, remod for hydrographic work and for light trawling assigned to the Ashland station. These two ves are equipped with most of the latest devices sampling, measuring, recording, and analy limnological features of the lakes. The *Musk* is a 45-foot trap net boat assigned to the

y station. She is well equipped for limno-
al sampling in shallower waters of the lakes.
w 65-foot vessel, the *Kaho*, has been built for
ratory fishing and gear research.
mnological research has consisted of general
eys, studies on particular unit problems,
long-term investigations. These divisions also
ct the development of the research program.
eneral fishery and limnological surveys we e
e in Lake Michigan in 1951, 1952, 1954,
, 1960, and 1961; Lake Huron in 1952 and
; Lake Superior in 1952, 1953, and 1959;
in Lake Erie in 1957 and 1958. Data from
e surveys have been published as a complete
(Beeton *et al.*, 1959) or used in special
ies of currents (Johnson, 1960) and plankton
lls, 1960). Considerable material has been
l by graduate students in their studies for
ters' or doctoral degrees.

he Bureau of Commercial Fisheries has par-
pated in a number of special studies. The
au cooperated with the Great Lakes Research
itute and Ontario Department of Lands and
ests in the synoptic surveys of Lake Huron
1954. Three synoptic surveys were made in
inaw Bay in 1956 in cooperation with the
higan Department of Conservation. Three 3-
synoptics were completed in western Lake
e in 1958 in cooperation with the Ohio Divi-
of Wildlife. The bureau, Great Lakes Insti-
e, Ohio Division of Wildlife, Ohio Division of
re Erosion, Stone Laboratory of Ohio State
iversity, Ontario Department of Lands and
rests, and Pennsylvania Fish Commission took
t in one or more of the surveys made of Lake
e in 1959, 1960, and 1961. The M/V *Siscowet*
s used for preliminary survey of possible coring
es in the bottom-coring project conducted by
University of Minnesota and the Great Lakes
search Division in 1961.

A major weakness in Great Lakes research is
lack of long-term studies. Most of the past
dies have the common fault of showing only
conditions existing during a short time in a
rticular area. To correct this situation, the
reau has undertaken limnological and fishery
servations that will be made routinely for a
g time. Areas of the lakes have been tenta-
ely subdivided into ecological zones. A number
"index stations," which are assumed to be
resentative of these zones, have been estab-
ed. Sampling of most aspects of the environ-

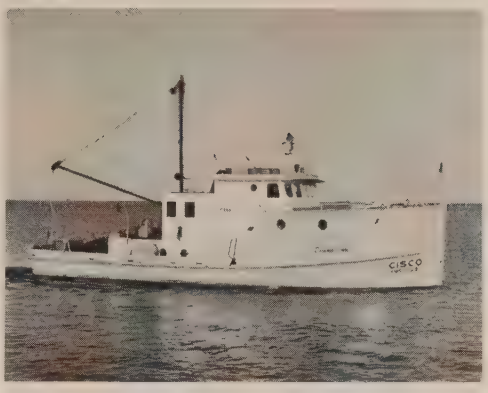


Fig. 19.4.—M/V *Cisco*, U.S. Bureau of Commercial Fisheries.

ment is conducted at these stations several times each year. Periodic review of materials and observations will indicate any need for changes in procedure or station locations. It is anticipated that various instruments and systems, such as the unmanned buoy system, being developed by oceanographers will be very useful in this program.

U.S. Lake Survey.—The U.S. Lake Survey, Army Corps of Engineers, is one of the oldest agencies working on the Great Lakes. It had its origin in 1841 when the Congress of the United States appropriated funds for a "Hydrographical Survey of the Northern and Northwestern Lakes." By 1882 all of the designated waters had been charted, and the agency was disbanded except for reproducing charts as stocks became exhausted. Funds were increased in 1889 to make additional surveys to correct the charts. These early surveys covered depths only to 18 ft. By the turn of the century, however, the rapid development of the manufacturing and shipping industries around the lakes made it obvious that the method of keeping the charts up to date was inadequate and that depths charted only to 18 ft were too shallow. Consequently, the U.S. Lake Survey was reorganized in 1901 and has been continuously active since.

The Lake Survey is authorized and directed to conduct all necessary activities to provide charts and related information for the safe navigation of all classes of vessels within the United States portion of the Great Lakes and their connecting and outflow waters. Hydrographic surveys have been conducted on all of the Great Lakes and connecting waters. A program of re-sounding the deep

Fig. 19.5.—M/V *Williams* used in sounding deep areas of the lakes by the U.S. Lake Survey.

areas of the lakes, which was initiated in 1945 and completed in 1960, covered approximately 58,600 mi^2 of open water with sounding lines approximately 1½ mi apart (Fig. 19.5). Water temperatures, meteorological data, and bottom sediments were collected. Inshore sounding from the shoreline to the five-fathom contour covered approximately 800 mi of coast line and about 300 mi of rivers with sounding lines spaced approximately 1,000 ft apart.

Hydraulic and hydrologic work includes continuous measurement of water levels of the lakes and their connecting rivers (the Lake Survey has approximately 50 recording gauges throughout the Great Lakes area) and periodic measurement of flows in the connecting rivers from which stage-discharge relationships have been developed for all ranges of lake stages. In addition many studies have been conducted to determine the effects of construction, water diversions, and dredging on Great Lakes water levels.

The first seasonal forecast of lake levels was issued in 1952. A consecutive six-month forecast replaced the seasonal forecast in 1958. Statistical analysis was made of the factors affecting lake levels, and investigations were made of factors affecting water supplies to the lakes. Currently an extensive study is being made of these individual factors.

Numerous investigations have been made on the effects of diversion into and out of the Great Lakes and on the effects of channel changes on lake levels. Several studies have been completed on evaporation from the lakes. Precipitation gauges were established in northeastern Lake Michigan in 1952 for a ten-year study of overland and overwater precipitation (Blust and DeCooke, 1960).

Great Lakes Research Division, University Michigan.—The Board of Regents of the Univ sity of Michigan established a Great Lakes search Institute on 16 May 1945 ". . . for encouragement and integration of studies of physical, chemical, biological, and other aspects the Great Lakes and related areas." It has fu tioned as a research organization in the broad sense with the objectives of stimulation, pror tion, and coordination of research on the Gr Lakes, as well as the implementation of the u versity's relevant teaching and research progra

On 1 April 1960 the Great Lakes Resea Institute was reorganized as the Great La Research Division of the Institute of Science a Technology at the University of Michigan. T reorganization provided the division with a m satisfactory administrative position in the univ sity, a broader base for establishing a resea program, and greater facilities and financial ass ance. Its objectives were not altered, howe by the reorganization.

Administration of this organization in 1945- was carried out by a twelve-man Council; chairman served as the administrative offi Chairmen of the Council were Paul S. Wel Professor of Zoology, 1945–47; Frederick Sparrow, Jr., Professor of Botany, 1948– Earnest Boyce, Professor of Sanitary Engineeri 1951; James T. Wilson, Professor of Geolo 1952–55; David C. Chandler, Professor of Zo ogy, 1956–59. Administration of the Great La Research Division is now carried out by a Dir tor, David C. Chandler, assisted by a twelve-m Council and an Advisory Committee.

Since 1947 the university has supplied institute and the division with a modest operat budget. Major support for the research progra however, is obtained from outside agencies the form of grants, fellowships, and contra

Research prior to 1954 represented efforts individuals encouraged but not financially s ported by the institute. Corings of sediments Lake Erie were made in 1948 and 1949 by Jar T. Wilson. Investigation of benthos of no eastern Lake Michigan in 1952 and plank studies of Lake Superior in 1953 were made David C. Chandler. These early studies and conference on the Upper Great Lakes, sponso by the institute at the University of Michi Biological Station in the summer of 1953, ser as a basis for the establishment of a larger tegrated program continuous since 1954.

ive general areas of research were emphasized he program from 1954 to 1961: currents and er masses, biology, geology, water quality, meteorology. These studies, although diverse of varying degrees of intensity, contributed to or more of the following problems of water ources of the Great Lakes: water budget, er quality, translocation and circulation, air- er interface phenomena, effects of Great Lakes regional meteorological conditions, ice cover, nology of the Great Lakes, erosion and osition, nature of lake basins, biological pro- tivity, and biological resources. A list of the lications resulting from the various projects published in the Proceedings of the Fourth nference on Great Lakes Research (Ayers, 1).

During the summer of 1954, the institute perated with the Ontario Department of Lands d Forests and the U.S. Fish and Wildlife Service a mutiple-ship synoptic survey of temperature nditions, chemical characteristics, and currents Lake Huron. The following summer a simi- study was made of Lake Michigan. Both dies were aimed at determining the main cur- nt patterns and characteristics of the water culation. These investigations, in addition to se made of the water transport in the Straits Mackinac in 1956 and the physical limnology Grand Traverse Bay in 1954, represent the ajor studies of currents by the Great Lakes esearch Division.

The biological program has been continuous nce 1955, concentrating on studies of benthos, imary productivity, and microorganisms. From 55 to 1959 emphasis was placed on the relation benthic organisms to sediments and currents upper Lakes Michigan and Huron. In an area 640 mi² more than 690 samples of sediment ere collected for mechanical analysis and study organisms (Lauff *et al.*, 1961). A similar study as conducted on Grand Traverse Bay during 57 and 1958. Measurements of *in situ* integral otosynthesis by means of carbon-14 were made Lake Huron in 1955 and in Grand Traverse Bay 1959 and 1961. The latter studies compared *situ* and calculated integral photosynthesis and veloped a synoptic method for measuring pri- ary productivity (Bachmann *et al.*, 1961). reliminary studies have been made in Grand raverse Bay on the distribution and abundance bacteria in water and fungi in the sediments. Geological studies consisting of sediment coring to determine the Lake Stanley low-water stage in Lake Huron and to construct the geological history of northern Lake Michigan were made in 1957 and 1958. In 1961 extensive coring was done in Lake Superior from an oil-well drilling ship to obtain combinations of punched and drilled cores through the sediment layers to bedrock. Studies of the chemistry and physical chemistry of trace elements in the overlying waters, interstitial waters, and sediments of several of the Great Lakes were initiated in 1961. Factors influencing the determination of recent rates of crustal uplift in the Great Lakes region were investigated in 1960.

Two major studies have been made of water quality and lake eutrophication. In 1957 and 1958 the location of sources and repositories of limnological and meteorological data pertaining to the Great Lakes was compiled to further the understanding of past events in the lakes and the detection of future trends (Powers *et al.*, 1960). These studies were intensified in 1961, when a four-year program was begun for the evaluation of the climatological, hydrological, limnological, and human factors affecting water quality. The ultimate aim was to analyze the causes of existing deterioration and to develop means for predicting future rates of deterioration.

Meteorological studies have been carried on by the division in various forms since 1954. The major studies concern the structure of atmospheric turbulence at the air-water interface in selected portions of Lake Michigan (Portman *et al.*, 1961) and atmospheric diffusion in transitional states (Brock and Hewson, 1961). These studies contribute to fundamental knowledge of evaporation over water—information greatly needed for accurate prediction of water levels—and contribute to the solution of air-pollution problems.

The division owns well-equipped 34-foot and 49-foot research vessels for inshore studies and a 114-foot motor vessel for open-lake investigations and large-scale operations (Fig. 19.6). Plans are under way to acquire other research vessels to meet the needs of the division's expanding program.

In May 1961 the university acquired the use of State Ferry Pier No. 3 at St. Ignace, Michigan. This property consists of two piers more than 200 ft long, four slips with depths of 20 ft or more, and about two acres of land suitable for construction of shops and shore laboratories. The division will use these facilities cooperatively with

Fig. 19.6.—M/V *Inland Seas,* Great Lakes Research Division, University of Michigan.

other institutions as a base of operations for research in the lakes.

University of Minnesota.—The School of Public Health, University of Minnesota, initiated limnological studies of Lake Superior in 1955. The work of this group has been purposely varied to provide a broad basis for future research. The reports for 1956 and 1957 dealt with physical limnology (currents and temperatures); those for 1958 and 1959 concerned nutrients and the chemical characteristics of the lake waters. Recent studies have dealt with the distribution, abundance, and productivity of plankton (Putnam and Olson, 1961). The research has been supported by the Minnesota Department of Health, the U.S. Public Health Service, and the University of Minnesota.

Herbert M. Bosch has been responsible for the project administration, and the technical work has been under the direction of Theodore A. Olson. Dr. A. C. Redfield, Woods Hole Oceanographic Institution, has served as consultant.

The limnological laboratory is presently situated in the old Federal Fish Hatchery Building at Duluth, Minnesota. The interior of this building has been remodeled, and it is now called the "Lake Superior Research Station, University of Minnesota, at Duluth" (Fig. 19.7).

A greatly expanded program is anticipated, since other disciplines within the university have an increased interest in limnology. A new unit was recently organized, which has been named "The University of Minnesota Limnological Research Center." The fields of public health, geophysics, ecology, game and fish management, parasitology, and geology are represented. P Gast, the present director, is a geologist. center will be concerned with smaller lakes well as the large bodies of water. It is anticipa that the Limnological Research Center ultimat will become an active sponsor of scientific stu in many fields and that it will provide the opp tunity and encouragement necessary to stimul a variety of research in all phases of limnolo

Ontario Department of Lands and Fore —Most of the Canadian research on the G Lakes within recent years has been carried out the Ontario Department of Lands and Fore Four research stations are maintained on Great Lakes by the province at Glenora Maple on Lake Ontario, Wheatley on Lake E and South Bay Mouth on Lake Huron. M of the research of these stations has been rected by F. E. J. Fry, University of Toro W. J. Christie is in charge of the Glen station, R. G. Ferguson the Wheatley stati and John Budd the South Bay Mouth stati Land has been acquired for a new laborat building at Wheatley, and a new research ves the *Keenosay,* was commissioned for work Lake Erie in 1958. The vessel *Atigamayg* is signed to the South Bay Station and *Namaycush* to the Glenora station. These tions are primarily concerned with fishery search, although a laboratory for experime limnology was established at the Southern search Station at Maple in 1948. Investi tions at this laboratory have been concer with the effects of environmental factors, es cially temperature and low dissolved-oxy concentrations, on various species of trout other fish. Among the limnological studies c ducted at the South Bay Station are the syn tic surveys of Georgian Bay in 1953 and 19 McCombie's (1959) work on the relations

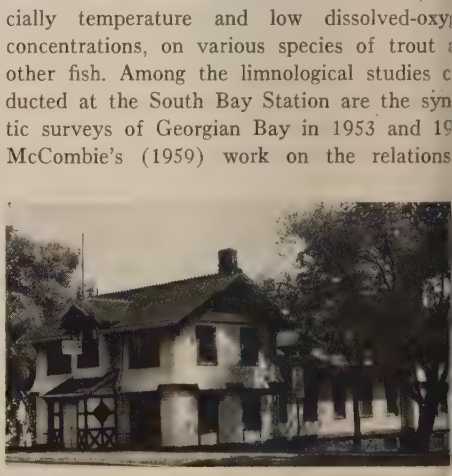


Fig. 19.7.—Lake Superior Research Station, Uni sity of Minnesota, Duluth, Minnesota.

een air and water temperatures, and an in- gation of mixing caused by seiches in South (Bryson and Stearns, 1959). Information on fishery research programs conducted at these ons and elsewhere by the department has presented by Loftus (1960).

or several years the Department of Lands Forests sponsored a physics program, under direction of D. V. Anderson, which was olved almost entirely with temperature, cur- s, winds, waves, bottom sediments, water ls, and their seasonal variations. The re- ch capability of this unit was greatly ex- ded when the C.M.S. *Porte Dauphine,* a -foot, 400-ton, trawler-type vessel, was ed to the department by the Royal Ca- ian Navy. She was operated in Lake Ontario 1958 on a trial program conducted by the artment on behalf of participating agencies the Great Lakes Geophysical Research up. This group was established in 1958 for mulation of recommendations, promotion, l liaison of research programs among various nadian agencies. The *Porte Dauphine* made veys in Lakes Erie, Huron, Ontario, and perior in 1959. The study of the energy dget of Lake Ontario by Rodgers and Ander- (1961) is based on data from these sur- ys. The general program received support m the Ontario Hydro, Department of Na- nal Defense, Meteorological Branch of the partment of Transport, Hydrographic Serv- of the Department of Mines and Technical rveys, and various Canadian oil companies.

Great Lakes Institute, University of To- nto.—The Great Lakes Institute, established the University of Toronto in 1960, replaced e Great Lakes Geophysical Research Group. ost of the individuals concerned with the eophysical Research Group are now connected ith the institute. G. B. Langford, Head, De- rtment of Geological Sciences, University of oronto, is the Director of the institute. R. E. eane is Director of Research, and F. E. J. y is Associate Director of Research. Limno- gical work is being carried out by investiga- rs from the University of Western Ontario, eteorological Branch of the Department of ransport, Ontario Water Resources Commis- on, and McMaster University, as well as the niversity of Toronto.

Extensive surveys of each of the lakes form e nucleus of the institute's research program. A grid of stations has been established on a lake, and each station is occupied by the *Porte Dauphine* once a month. Data are gathered for each of the institute's programs in chemistry, meteorology, geology, physics, and zoology. Surveys are to be continued on a lake for two successive years to reduce the possibility of bias from abnormal conditions. Lake Ontario has been surveyed for two summers and one winter and Lake Erie for two summers. Several cruises have been made in Lakes Huron and Superior. Special cruises are arranged to study aspects of the geology, geochemistry, and geophysics of the lake basins (Langford, 1961).

The nature of the research program is apparent from the accomplishments of 1960. Meteorological studies included synoptic weather observations every three hours while the *Porte Dauphine* was underway. Gimbal-mounted rain gauges and an Eppley pyrheliometer, rubber-strip ozone samplers, a Hernion sampler, and a swing boom with instrumentation to measure wind velocity, temperature, and humidity at various heights above the water were installed aboard the *Porte Dauphine.* Sampling to detect pollution was conducted in cooperation with the Ontario Water Resources Commission. Quantitative sampling for plankton was carried out in Lakes Erie, Huron, and Ontario. Some of the samples are being analyzed for trace elements. A seismic study of the bed of Lake Erie was undertaken in cooperation with the Lamont Geological Observatory of Columbia University. Current studies, bottom sampling, and coring were conducted in Lakes Erie and Ontario.

U.S. Public Health Service.—The U.S. Public Health Service was authorized in 1960 to develop a comprehensive water-pollution-control program for the Great Lakes and the Illinois River basins. This authorization resulted from growing concern over the problem of maintaining the quality of our fresh waters despite a rapidly expanding population that makes greater and greater demands on this resource.

Laboratory facilities have been set up in Chicago, and a limnology section headed by James L. Verber has been established. Present plans call for intensive one-year limnological surveys of each of the lakes during the next five years. The initial study is being made in Lake Michigan, since information resulting from this study will be pertinent to the hearings on the diversion of water from Lake Michigan. Plans have been

Fig. 19.8.—Unmanned buoy being lowered into position in Lake Michigan for the U.S. Public Health Service study of currents.

made for the installation of 35 buoy stations equipped with devices for measuring low-velocity water currents, water and air temperatures, and wind direction and velocity (Fig. 19.8). A system of electronic interrogation is being considered for the telemetering of data to a shore-based communications center. Plans are being developed for a study of chemical and biological conditions. The U.S. Geological Survey will assist in stream gauging. The feasibility of constructing a model of Lake Michigan for water movement studies is being investigated by the U.S. Army Corps of Engineers (Poston, 1961).

Other organizations.—The various meteorological groups are concerned with the effects of the lakes on weather and climate of the region and the effects of various meteorological conditions on the lakes. The Canadian Meteorological Service and the U.S. Weather Bureau have equipped a number of lake ships with anemometers and water thermometers. Much of the Meteorological Service's work on automatic weather buoys or platforms, precipitation over land and water, water budgets, and the relation of gradient winds to water currents has been carried out in cooperation with the Great Lakes Institute, Univers of Toronto. J. P. Bruce, as Head of the H drometeorological Section, has taken an act part in research on Great Lakes problems. T U.S. Weather Bureau has been concerned w both the short-period (Harris, 1954) and long-term fluctuations (Brunk, 1960) in l levels. Studies at the University of Chicago, D partment of Meteorology, have centered arou the transfer of heat and moisture from the la to the atmosphere, the Great Lakes' influence the development of weather and motion syste (Petterssen, 1960), and numerical methods study of wind tides and surge (Platzman, 196

Geology now forms an integral part of several university organizations working on lakes. This situation did not exist until recent however, and Jack L. Hough, University of linois, had to rely upon assistance from the U Geological Survey, U.S. Fish and Wildlife Servi U.S. Lake Survey, Woods Hole Oceanograp Institution, and the U.S. Coast Guard during early phases of his work which led to the pu cation of the first comprehensive geological stu of the lakes in over 40 years (Hough, 195 Several of the states and the U.S. Geologi Survey are concerned with problems of sh erosion. The Ohio Division of Shore Erosion, n part of the Ohio Geological Survey, has had active research program on Lake Erie from 19 to the present. During this period the ent shoreline and the bottom deposits of the O portion of Lake Erie were mapped. Additio work has included studies of water levels, c rents, wind and water temperatures, and s bottom surveys. Howard J. Pincus, Ohio St University, has directed the program. R. P. Ha ley, geologist, and James L. Verber, hydrograph have been in charge of field operations.

Two organizations—the Great Lakes Comm sion and the Great Lakes Fishery Commissio have been established within recent years with ecutive offices in Ann Arbor. These organizati are not actively engaged in limnological resear nevertheless, we would be remiss not to ment them, for they have stimulated interest in a directed attention to important areas of resear Furthermore, they have supported the comp tion of two Great Lakes bibliographies. T Great Lakes Commission published the *Gr Lakes Fauna, Flora, and their Environment* John Van Oosten (1957). The Great Lakes Fi ery Commission contracted with the Univers

LE 19.3

ries of organizations having the Great Lakes ry Commission Bibliography in working order

au of Commercial sheries . Fish and Wildlife rvice gical Laboratory Arbor, Michigan	Minnesota Conservation Department Bureau of Research and Planning Division of Fish and Game 390 Centennial Office Building St. Paul, Minnesota
artment of Health, lucation and Welfare ic Health Service W. Pershing Road ago 9, Illinois	Research Branch Ontario Department of Lands and Forests Maple, Ontario
eries Research Board Canada ogical Station don, Ontario	Ontario Fisheries Research Laboratory Library University of Toronto Toronto, Ontario
at Lakes Fishery Commission Natural Resources uilding versity of Michigan n Arbor, Michigan	University of Michigan Natural Science Library Ann Arbor, Michigan
	University of Minnesota School of Public Health Minneapolis, Minnesota
titute for Fisheries Research seums Annex iversity of Michigan n Arbor, Michigan	Western Reserve University Dr. C. C. Davis Department of Zoology Cleveland, Ohio

Toronto for the compilation of a subject and thor filing-card index to the scientific literature. out 20 copies of the file have been established libraries in the Great Lakes region, including ose shown in Table 19.3.

The Great Lakes Commission was established 1955 by the Great Lakes Basin Compact as official agency of six Great Lakes states. It ceives support by equal legislative appropriaons from the member states. The commission concerned with all aspects of the development, e, and protection of the waters of the lakes cluding commerce, fisheries, lake levels and version, pollution and water supply, recreation, d transportation. Although it is concerned with search, its research function is principally that dissemination of information on the aforeentioned aspects of the lakes. The commission blishes the *Great Lakes News Letter* and coerates with the Great Lakes Research Division, niversity of Michigan, in the publication of the *reat Lakes Research Checklist*. Marvin Fast is e Executive Director, and Albert Ballert is the irector of Research.

The Great Lakes Fishery Commission was established by treaty between the United States and Canada in 1955. This commission is charged with the implementation of a program for control of the sea lamprey and coordination of fishery research by various agencies. The operational phase of the program is contracted to the U.S. Bureau of Commercial Fisheries and the Fisheries Research Board of Canada. The commission has not found it necessary to undertake a research program, although it has the authority to do so, and it has functioned to formulate and coordinate research programs. In addition to the major problem of sea lamprey control, it has been especially concerned with the eventual rehabilitation of the lake trout. Norman Baldwin is the Executive Secretary, assisted by Robert Saalfeld.

It should be apparent that the research effort on the Great Lakes has been greatly intensified during the past decade. Many state and federal organizations of both the United States and Canada have active research programs under way, and although little of the information being accumulated has yet been published, we can confidently anticipate that our knowledge of the limnology and fisheries of the Great Lakes will rapidly expand.

References

Adams, M. P. 1937. Saginaw Valley report. Michigan Stream Control Comm., 156 p.

Agassiz, Louis. 1850. Lake Superior: Its physical character, vegetation, and animals. (Narrative of the tour by J. Elliot Cabot). Gould, Kendall, and Lincoln, Boston. 428 p.

Ahlstrom, E. H. 1936. The deep-water plankton of Lake Michigan, exclusive of the Crustacea. Trans. Amer. Microscop. Soc., **55**: 286–299.

Andrews, T. F. 1953. Seasonal variations in relative abundance of *Cyclops vernalis* Fischer, *Cyclops bicuspidatus* Claus, and *Mesocyclops leuckarti* (Claus) in western Lake Erie, from July, 1946, to May, 1948. Ohio J. Sci., **53**: 91–100.

Applegate, V. C., and J. W. Moffett. 1955. The sea lamprey. Sci. Amer., **192**: 36–41.

Ayers, J. C. 1956. A dynamic height method for the determination of currents in deep lakes. Limnol. Oceanogr., **1**: 150–161.

———. 1961. Great Lakes Research Division. Univ. Michigan, Great Lakes Research Div., Publ. No. 7: 205–213.

Ayers, J. C., D. V. Anderson, D. C. Chandler, and G. H. Lauff. 1956. Currents and water masses of Lake Huron. Univ. Michigan, Great Lakes Research Inst., Tech. Paper No. 1, 219 p.

Ayers, J. C., D. C. Chandler, G. H. Lauff, C. F. Powers, and E. B. Henson. 1958. Currents and water masses of Lake Michigan. Univ. Michigan, Great Lakes Research Inst., Publ. No. 3, 169 p.

BACHMANN, R. W., G. W. SAUNDERS, AND F. B. TRAMA. 1961. Investigations in lake metabolism—photosynthesis: A modified C^{14} technique for estimations of photosynthesis in large lakes. Univ. Michigan, Great Lakes Research Div., Publ. No. 7: 163 (Abstract).

BAJORUNAS, L. 1960. Littoral transport in the Great Lakes. Proc. 7th Conf. Coastal Engr., Univ. California, Council Wave Research: 326–341.

BEETON, A. M. 1960. The vertical migration of *Mysis relicta* in Lakes Huron and Michigan. J. Fish. Research Board Canada, **17**: 517–539.

———. 1961. Environmental changes in Lake Erie. Trans. Amer. Fish. Soc., **90**: 153–159.

BEETON, A. M., AND F. W. HOOPER. 1961. The hydrography of Saginaw Bay. Univ. Michigan, Great Lakes Research Div., Publ. No. 7: 111 (Abstract).

BEETON, A. M., J. H. JOHNSON, AND S. H. SMITH. 1959. Lake Superior limnological data. U.S. Fish and Wildl. Serv., Spec. Sci. Rept., Fish. No. 297, 177 p.

BIRGE, E. A. 1881. Notes on Crustacea in the Chicago water supply, with a note on the formation of the carapace. Med. J. Examiner, **14**: 584–590.

BLUST, F., AND B. G. DECOOKE. 1960. Comparison of precipitation on islands of Lake Michigan with precipitation on the perimeter of the lake. J. Geophys. Research, **65**: 1565–1572.

BRIGGS, S. A. 1872. The Diatomaceae of Lake Michigan. The Lens, **1**: 41–44.

BRITT, N. W. 1955. Stratification in western Lake Erie in summer of 1953: Effects on the *Hexagenia* (Ephemeroptera) population. Ecology, **36**: 239–244.

BROCK, F. V., AND E. W. HEWSON. 1961. Analog computing techniques applied to atmospheric diffusion: Continuous point source. Univ. Michigan, Great Lakes Research Div., Spec. Rept. 12, 56 p.

BRUNK, I. W. 1960. Precipitation and the levels of Lakes Michigan and Huron. Univ. Michigan, Great Lakes Research Div., Publ. No. 7: 145–150.

BRYSON, R. A., AND C. R. STEARNS. 1959. A mechanism for the mixing of the waters of Lake Huron and South Bay, Manitoulin Island. Limnol. Oceanogr., **4**: 246–251.

CHANDLER, D. C., AND O. B. WEEKS. 1945. Limnological studies of western Lake Erie. V. Relation of limnological and meteorological conditions to the production of phytoplankton in 1942. Ecol. Monogr., **15**: 435–456.

CHURCH, P. E. 1942. The annual temperature cycle of Lake Michigan. I. Cooling from late autumn to the terminal point, 1941–42. Univ. Chicago Inst. Meteorol., Misc. Rept. 4, 48 p.

———. 1945. The annual temperature cycle of Lake Michigan. II. Spring warming and summer stationary periods, 1942. Univ. Chicago Inst. Meteorol., Misc. Rept. 18, 100 p.

CLARK, L. J. 1892. Currents in Lake Ontario. Trans. Canadian Inst., **2**: 154–157.

COMSTOCK, C. B. 1872. Tides at Milwaukee, Wis. U.S. Engr., Ann. Rept., Appendix A: 1035–1040.

CORPS OF ENGINEERS, U.S. ARMY. 1960. Great Lakes pilot. U.S. Lake Surv., Detroit, 451 p.

CROHURST, H. R., AND M. V. VELDEE. 1927. Report of an investigation of the pollution of Lake Mic gan in the vicinity of South Chicago and the Ca met and Indiana Harbors, 1924–25. U.S. P Health Bull. 170, 134 p.

DAMANN, K. E. 1960. Plankton studies of La Michigan. II. Thirty-three years of continu plankton and coliform bacteria data collected fr Lake Michigan at Chicago, Illinois. Trans. Am Microscop. Soc., **79**: 397–404.

DAVIS, C. C. 1954. A preliminary study of the pla ton of the Cleveland Harbor area, Ohio. III. zooplankton, and general ecological considerati of phytoplankton and zooplankton producti Ohio J. Sci., **54**: 338–408.

———. 1955. A preliminary study of industrial pol tion in the Cleveland Harbor area, Ohio. IV. Pla ton and industrial pollution in Cleveland Harb Sewage and Ind. Wastes, **27**: 835–850.

DEARBORN, H. A. S. 1829. On the variations of le in the great North American Lakes, with do ments. Amer. J. Sci., Arts, **16**: 78–94.

DEASON, H. J. 1932. A study of surface currents Lake Michigan. The Fisherman, 1: 3–4, 12.

DEWEY, C. 1838. Temperature of Lake Onta Amer. J. Sci., **33**: 403–405.

DOLE, R. B. 1909. The quality of surface waters the United States. I. Analyses of waters east of one hundredth meridian. U.S. Geol. Surv., Wa Supply Paper 236, 123 p.

DONN, W. L., AND MAURICE EWING. 1956. Stok edge waves in Lake Michigan. Science, **124**: 12 1242.

DRUMMOND, A. T. 1890. Some temperatures in Great Lakes and St. Lawrence. Canadian Rec Sci., **4**: 77–85.

EDDY, SAMUEL. 1943. Limnological notes on La Superior. Proc. Minnesota Acad. Sci., **11**: 34–39

EGGLETON, F. E. 1937. Productivity of the profun benthic zone in Lake Michigan. Papers Michig Acad. Sci Arts Lett., **22**: 593–611.

FELL, G. E. 1910. The currents at the easterly e of Lake Erie and head of Niagara River: Th influence on the sanitation of the city of Buff N.Y. J. Amer. Med. Assoc., **55**: 828–834.

FISH, C. J. 1960. Limnological survey of eastern a central Lake Erie 1928–29. U.S. Fish and Wi Serv., Spec. Sci. Rept., Fish. No. 334, 198 p.

FORBES, S. A. 1891. On some Lake Superior En mostraca. U.S. Comm. Fish. Rept. (1887): 7 718.

GILLIES, D. K. A. 1960. Winds and water levels Lake Erie. Univ. Michigan, Great Lakes Resea Div., Publ. No. 4: 35–42.

GOODRICH, CALVIN, AND HENRY VAN DER SCHA 1932. The naiad species of the Great Lakes. Oc sional Papers, Museum Zool., Univ. Michigan, 238, 14 p.

GOTTSCHALL, R. Y., AND O. E. JENNINGS. 1933. Li nological studies at Erie, Pennsylvania. Tra Amer. Microscop. Soc., **52**: 181–191.

GRAHAM, J. D. 1861. Investigation of the probl regarding the existence of a lunar tidal wave on great freshwater lakes of North America. Pr Amer. Assoc. Advance. Sci. (1860): 52–60.

CHEY, H. B. 1952. Vertical temperature distribution in the Great Lakes. J. Fish. Research Board Canada, **9**: 323–328.

RRINGTON, M. W. 1895. Currents of the Great Lakes, as deduced from the movements of bottle papers during the seasons of 1892, 1893, and 1894. U.S. Dept. Agr., Weather Bur. Bull. B, 14 p.

RRIS, D. L. 1954. Wind tide and seiches in the Great Lakes. Proc. 4th Conf. Coastal Engr., Univ. California, Council Wave Research: 25–51.

——. 1957. The effect of a moving pressure disturbance on the water level in a lake. Meteorol. Monogr., **2**: 46–57.

YFORD, J. F. 1922. Effects of winds and of barometric pressures on the Great Lakes. Carnegie Inst. Wash., Publ. No. 217, 133 p.

NRY, A. J. 1900. Lake levels and wind phenomenon. Monthly Weather Rev., **28**: 203–205.

E, RALPH. 1957. U.S. federal fishery research on the Great Lakes through 1956. U.S. Fish and Wildl. Serv., Spec. Sci. Rept., Fish. No. 226, 46 p.

RTON, R. E., AND C. E. GRUNSKY. 1927. Hydrology of the Great Lakes. Rept. Engr. Board Rev., Sanit. District Chicago, Part III, Appendix II, 432 p.

UGH, J. L. 1958. Geology of the Great Lakes. Univ. Illinois Press, Urbana. 313 p.

Y, P. R. 1872. Deep water fauna of Lake Michigan. Trans. Wisconsin Acad. Sci. Arts Lett., **1**: 98–101.

NT, I. A., JR. 1958. Winds, wind set-ups, and seiches on Lake Erie. U.S. Lake Surv., Corps of Engr. (Paper presented at 2nd Natl. Conf. on Appl. Meteorol., Ann Arbor), 37 p. (Mimeo.)

TERNATIONAL BOARD OF INQUIRY. 1943. Report of the International Board of Inquiry for the Great Lakes fisheries. U.S. Govt. Printing Office, Washington. 213 p.

TERNATIONAL JOINT COMMISSION. 1951. Report of the International Joint Commission United States and Canada on pollution of boundary waters. Washington and Ottawa, 312 p.

NNINGS, H. S. 1904. Rotatoria of the United States. II. A monograph of the Rattulidae. Bull. U.S. Fish. Comm. (1902), Part 2, **22**: 273–352.

ROME, G. M. 1879. Third Biennial Report. Michigan State Board Fish. Comm. (1877–78), 96 p.

HNSON, J. H. 1958. Surface-current studies of Saginaw Bay and Lake Huron, 1956. U.S. Fish and Wildl. Serv., Spec. Sci. Rept., Fish. No. 267, 84 p.

——. 1960. Surface currents in Lake Michigan, 1954 and 1955. U.S. Fish and Wildl. Serv., Spec. Sci. Rept., Fish. No. 338, 120 p.

ELLICOTT, D. S. 1878. Notes on microscopic life in the Buffalo water supply. Amer. J. Microscop. Pop. Sci., **3**: 250–252.

DELZ, W. N. 1929. Coregonid fishes of the Great Lakes. Bull. U.S. Bur. Fish., **43**: 297–643.

KE MICHIGAN WATER COMMISSION. 1911. Second Report. 204 p.

NE, A. C. 1899. Lower Michigan waters: A study into the connection between their chemical composition and mode of occurrence. U.S. Geol. Surv., Water-supply Irrigation, Paper 31, 97 p.

NGFORD, G. B. 1961. The Canadian Great Lakes research program. Univ. Michigan, Great Lakes Research Div., Publ. No. 7: 199–201.

LANGLOIS, T. H. 1949. The biological station of the Ohio State University. Franz Theodore Stone Lab., Contrib. No. 11, 64 p.

LAUFF, G. H., E. B. HENSON, J. C. AYERS, D. C. CHANDLER, AND C. F. POWERS. 1961. The bottom sediments of the Straits of Mackinac region. Univ. Michigan, Great Lakes Research Div., Publ. No. 6, 69 p.

LEVERIN, H. A. 1947. Industrial waters of Canada. Report on investigations, 1934 to 1943. Canadian Dept. Mines Research, Mines Geol. Branch, Rept. No. 819, 109 p.

LEVERETT, FRANK, AND F. B. TAYLOR. 1915. The Pleistocene of Indiana and Michigan, and the history of the Great Lakes. Monogr. U.S. Geol. Surv., **53**: 1–529.

LOFTUS, K. H. 1960. Current status of fisheries research projects. Univ. Michigan, Great Lakes Research Div., Publ. No. 4: 115–119.

MCCOMBIE, A. M. 1959. Some relations between air temperatures and the surface water temperatures of lakes. Limnol. Oceanogr., **4**: 252–258.

MARSH, C. D. 1895. Cyclopidae and Calanidae of Lake St. Clair, Lake Michigan, and certain of the inland lakes of Michigan. Bull. Michigan Fish Comm., No. 5, 24 p.

MERNA, JAMES. 1960. A benthological investigation of Lake Michigan. Masters Thesis, Michigan State Univ., 74 p.

MILLAR, F. G. 1952. Surface temperatures of the Great Lakes. J. Fish. Research Board Canada, **9**: 329–376.

MILLS, HENRY. 1882. Microscopic organisms in the Buffalo water-supply and in Niagara River. Proc. Amer. Soc. Microscop., 5th Ann. Meeting: 165–175.

MILNER, J. W. 1874. Report on the fisheries of the Great Lakes. U.S. Comm. Fish. Rept. (1872–73), Part 2: 1–78.

MOFFETT, J. W. 1957. Recent changes in the deep-water fish populations of Lake Michigan. Trans. Amer. Fish. Soc., **86**: 393–408.

MOORE, J. P. 1906. Hirudinea and Oligochaeta collected in the Great Lakes region. Bull. U.S. Bur. Fish., **25**: 153–171.

NEW YORK CONSERVATION DEPARTMENT. 1929. A biological survey of the Erie-Niagara system. 18th Ann. Rept. (1928), Suppl., 244 p.

NEW YORK STATE DEPARTMENT OF HEALTH. 1958. Lake Ontario surface water including specified tributaries. Lake Ontario Drainage Basin Surv. Ser., Rept. No. 4, 447 p.

NICHOLSON, H. A. 1872. Preliminary report on dredgings in Lake Ontario. Ann. Mag. Nat. Hist., Ser. 4, **10**: 276–284.

OHIO DEPARTMENT OF NATURAL RESOURCES. 1953. Lake Erie Pollution Survey. Final Rept., 201 p.

PERKINS, E. A. 1893. The seiches in American lakes. Amer. Meteorol. J., **10**: 251–263.

PETTERSSEN, SVERRE. 1960. Some weather influences due to warming of the air by the Great Lakes in

winter. Univ. Michigan, Great Lakes Research Div., Publ. No. 4: 9–20.

PIETERS, A. J. 1894. The plants of Lake St. Clair. Bull. Michigan Fish Comm., No. 2, 10 p.

PLATZMAN, GEORGE. 1960. A numerical computation of the surge of 26 June 1954 on Lake Michigan. Univ. Michigan, Great Lakes Research Div., Publ. No. 4: 21–25.

PORTMAN, D. J., F. C. ELDER, AND EDWARD RYZNAR. 1961. Research on energy exchange processes. Univ. Michigan, Great Lakes Research Div., Publ. No. 7: 96–109.

POSTON, H. W. 1961. The Great Lakes-Illinois Waterway basins comprehensive water pollution control project. Univ. Michigan, Great Lakes Research Div., Publ. No. 7: 57–63.

POWERS, C. F., D. L. JONES, AND J. C. AYERS. 1959. Sources of hydrographic and meteorological data on the Great Lakes. U.S. Fish and Wildl. Serv., Spec. Sci. Rept., Fish. No. 314, 183 p.

POWERS, C. F., D. L. JONES, P. C. MUNDINGER, AND J. C. AYERS. 1960. Applications of data collected along shore to conditions in Lake Erie. Univ. Michigan, Great Lakes Research Div., Publ. No. 5, 78 p.

PRINCE, E. E. 1915. Preface. Contributions to Canadian biology. II. Fresh-water fish and lake biology. Dept. Marine Fish., Fish Branch, Sessional Paper No. 396, Suppl. 47th Ann. Rept.: i, ii.

PUTNAM, H. D., AND T. A. OLSON. 1961. Studies on the productivity and plankton of Lake Superior. School Pub. Health, Univ. Minnesota, 72 p. (Mimeo.)

RATHBUN, RICHARD, AND WILLIAM WAKEHAM. 1897. Report of the Joint Commission relative to the preservation of the fisheries in waters contiguous to Canada and the United States. House of Representatives, 54th Congr., 2nd Session, Document No. 315, 178 p.

REIGHARD, J. E. 1893. Some plankton estimates in the Great Lakes. Trans. Amer. Fish. Soc., 1893: 112–122.

———. 1894. A biological examination of Lake St. Clair. Bull. Michigan Fish Comm., No. 4, 60 p.

———. 1899. A plan for the investigation of the biology of the Great Lakes. Trans. Amer. Fish. Soc., **28**: 65–71.

RODGERS, G. K., AND D. V. ANDERSON. 1961. A preliminary study of energy budget of Lake Ontario. J. Fish. Research Board Canada, **18**: 617–636.

RUSCHMEYER, O. R., T. A. OLSON, AND H. M. BOSCH. 1958. Water movements and temperatures of western Lake Superior. School Pub. Health, Univ. Minnesota, 65 p. (Mimeo.)

SCHERMERHORN, L. Y. 1887. Physical characteristics of the northern and northwestern lakes. Amer. J. Sci., Ser. 3, **33**: 278–284.

SCHUMACHER, R. E., AND SAMUEL EDDY. 1960. The appearance of pink salmon, *Oncorhynchus gorbuscha* (Walbaum), in Lake Superior. Trans. Amer. Fish. Soc., **89**: 371–373.

SCOTT, W. B., AND W. J. CHRISTIE. 1961. A review of the invasion of the lower Great Lakes by the white perch (*Roccus americanus*). Univ. Michigan, Great Lakes Research Div., Publ. No. 7: 1 (Abstract).

SMITH, H. M. 1894. Report on the fisheries of t Great Lakes. U.S. Comm. Fish. Rept. (1892), P 18: 361–462.

SMITH, S. I. 1874. Crustacea of the fresh waters the United States. U.S. Comm. Fish. Rept. (187 73), Part 2: 637–665.

SNOW, J. W. 1904. The plankton algae of Lake E with special reference to the Chlorophyceae. B U.S. Fish. Comm., **22**: 369–394.

TETER, H. E. 1960. The bottom fauna of Lake Hur Trans. Amer. Fish. Soc., **89**: 193–197.

THOMAS, B. W., AND H. H. CHASE. 1887. Diatom ceae of Lake Michigan as collected during the l sixteen years from the water supply of the city Chicago. Notarisia, Commentarium Phycologiu Anno 2, No. 6, 1887: 328–330.

U.S. COMMISSION OF FISH AND FISHERIES. 1900. R port for 1899: xxi, cxix.

VAN OOSTEN, JOHN. 1929. Life history of the la herring (*Leucichthys artedi* Le Sueur) of La Huron as revealed by its scales, with a critique the scale method. Bull. U.S. Bur. Fish., **44**: 26 428.

———. 1930. The disappearance of the Lake E cisco—a preliminary report. Trans. Amer. Fi Soc., **60**: 1–11.

———. 1957. Great Lakes fauna, flora, and th environment. Great Lakes Comm., Ann Arbor, p.

———. 1960. Temperatures of Lake Michigan, 193 32. U.S. Fish and Wildl. Serv., Spec. Sci. Re Fish. No. 322, 34 p.

———. 1962. Surface currents of Lake Michig 1931–32. In press.

VERBER, J. L. 1961. Long and short period oscil tions in Lake Erie. Ohio Div. Shore Erosion, 98 (Mimeo.)

VERDUIN, JACOB. 1956. Primary production in lak Limnol. Oceanogr., **1**: 85–91.

———. 1960. Phytoplankton communities of weste Lake Erie and the CO_2 and O_2 changes associat with them. Limnol. Oceanogr., **5**: 372–380.

VORCE, C. M. 1882. Microscopical forms observed water of Lake Erie. Proc. Amer. Soc. Microsco 5th Ann. Meeting: 187–196.

WARD, H. B. 1896. A biological examination of La Michigan in the Traverse Bay Region. Bull. Mi igan Fish Comm., No. 6, 99 p.

WELLS, LARUE. 1960. Seasonal abundance and ver cal movements of planktonic Crustacea in La Michigan. U.S. Fish and Wildl. Serv., Fish. Bu **60**: 343–369.

WILLIAMSON, B. L., AND JOHN GREENBANK. 19 Investigation of the pollution of the Fox and E rivers and of Green Bay in the vicinity of the c of Green Bay, 1938–39. Wisconsin Comm. Wa Pollution, Board Health, 242 p.

WRIGHT, STILLMAN. 1955. Limnological survey western Lake Erie. U.S. Fish and Wildl. Se Spec. Sci. Rept., Fish. No. 139, 341 p.

CARANX FASCIATUS CUVIER, AN UNIDENTIFIABLE NAME FOR A CARANGID FISH.—*Caranx fasciatus* Cuvier is here recorded as a *nomen dubium* for the following reasons.

1. This nominal species was based upon a drawing. Cuvier (*in* Cuvier and Valenciennes, 1833, *Hist. Nat. Poissons 9:70*) briefly described this species from a drawing from the collection of Mocigno and Sesse under the heading of "Le Caranx a Bandes, *Caranx fasciatus,* Coll. mexic." Cuvier stated that the drawing bore the label *"Scomber fasciatus"* and the common name "xurel"—possibly he intended to credit the authorship of this new species to Mocigno and Sesse, because the customary "nob." was not included in the heading. The drawing is published for the first time (Fig. 1) from a photograph furnished through the courtesy of Madame M. L. Bauchot, Museum National d'Histoire Naturelle.

2. The drawing is obviously lacking in technical accuracy. While this is understandable or excusable for drawings from this early era, the characters necessary for identification in this case are rendered undeterminable.

3. The characters of the drawing that can be determined do not relate, collectively, to any species of American carangid. The following diagnostic features can be determined or estimated from the drawing: D. VI, 17; A. II,

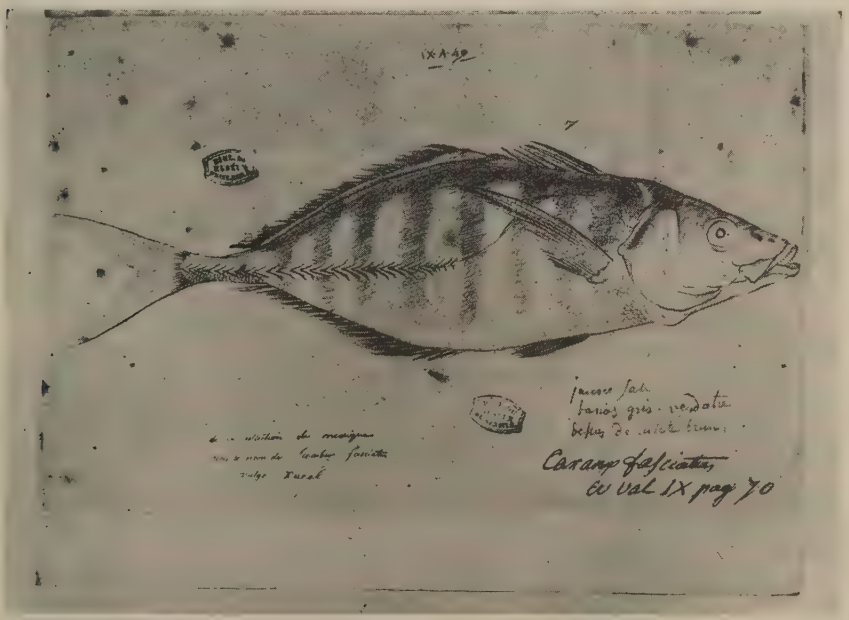


Fig. 1. Photograph of the original drawing of *Caranx fasciatus* Cuvier, *nomen dubium,* from the collection of Mocigno and Sesse in the Museum National d'Histoire Naturelle.

14; scutes 29; body bars 7 (plus one at nape); ratio of straight lateral line to curved about 1.4; chest completely scaled; profile of snout pointed. Four genera may be considered, *Uraspis, Carangoides, Hemicaranx,* and *Caranx (sensu lato)* — the drawing was probably of some species of *Caranx,* possibly *Caranx vinctus* Jordan and Gilbert, but it does not fit the descriptions of any American species of any of these genera.

4. The exact geographic origin of the specimen on which the drawing was based apparently cannot be determined. In the original description Cuvier only mentioned American Seas ("les mers d'Amérique). In the introduction to Cuvier and Valenciennes' *Histoire Naturelle des Poissons* Cuvier (1828:256) referred to a collection of beautiful drawings made for the king of Spain by M. Mocigno from the coasts of Mexico ("des côtes du Mexique"). References ascribing the type locality to the Atlantic or Gulf of Mexico were either based upon erroneous suppositions or on unrecorded information that is not currently available. Madame M. L. Bauchot examined pertinent records in the Paris Museum and found no mention of specific locality (personal communication, 4 Jan. 1962).

5. The name has had a vascillating taxonomic history, and no specimen has ever been adequately identified as this species. Jordan (1884, *Proc. Acad. Nat. Sci. Phila. p. 284*) recorded it as "an extremely doubtful synonym" of *Caranx vinctus.* The name was listed as a questionable synonym of *Hemicaranx secundus* (Poey) by Jordan and Evermann (1896, *Bull. U. S. Natl. Mus. [47, 1]: 914*). It was given as *Xurel fasciatus* (Cuvier) with *Caranx secundus* Poey in synonymy by Jordan, Evermann, and Clark (1930, *Rept. U. S. Comm. Fish. 10:272*). Based on subjective reasoning Berry (1959, *Fish. Bull. Fish Wildl. Serv 152:525*) regarded it as *Hemicaranx fasciatus* (Cuvier). Subsequent examination of the type specimens of *Caranx secundus* Poey, through the courtesy of Dr. Giles W. Mead, Museum of Comparative Zoology, Harvard University, has shown that Poey's species is in the genus *Uraspis* Bleeker. —Frederick H. Berry, *U. S. Bureau of Commercial Fisheries, Biological Laboratory, La Jolla, California.*

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GILLRAKER ANALYSIS AND SPECIATION IN THE THREAD HERRING GENUS *OPISTHONEMA*

by

Frederick H. Berry[1] and Izadore Barrett

SUMMARY

The thread herrings, genus *Opisthonema,* family Clupeidae, are marine fishes that occur only in tropical and subtropical waters off both coasts of the American continent. The genus is composed of one Atlantic species and four Pacific species. *Opisthonema oglinum* (LeSueur), the single species in the western Atlantic Ocean, occurs from Brazil to Massachusetts, at Bermuda, and throughout the West Indies. *Opisthonema libertate* (Günther), *Opisthonema bulleri* (Regan), and *Opisthonema medirastre,* new species, are Pacific coastal species which occur together from Peru to Mexico (with at least one occasionally in California). *Opisthonema berlangai,* new species, is confined to the vicinity of the Galapagos Islands.

The five species show only slight differences in most morphological characters. Practical separation of the species is based on a combination of two considerations: (1) geographical area of occurrence and (2) the pattern of increase in the numbers of gillrakers in relation to standard length.

The numbers of gillrakers on the three segments of the first gill arch increase with the growth of the fish to about 120 mm S.L. in *O. oglinum,* to increasingly larger sizes in *O. bulleri, O. medirastre,* and *O. berlangai,* and apparently throughout life in *O. libertate.* Counts and comparisons of the numbers of gillrakers on the ceratobranchial segment of the first gill arch are the most convenient method for separating the five species. Specimens from colder waters tend to have fewer gillrakers than those from warmer waters.

ACKNOWLEDGEMENTS

We are grateful to the following for the loan or gift of specimens and for information on specimens: Franklin G. Alverson, William H. Bayliff, Edward F. Klima, Antonio Landa, Clifford L. Peterson, and Hernán Sobrado, Inter-American Tropical Tuna Commission (IATTC); William W. Anderson and Jack W. Gehringer, U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries, Biological Laboratory, Brunswick, Georgia (BLBG); John C. Briggs and E. D. Lane, University of British Columbia, Institute of Fisheries (UBC); Harvey R. Bullis, Jr. and Johnny A. Butler, U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries, Biological Laboratory, Pascagoula, Mississippi; Daniel M. Cohen, U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries, Ichthyological Laboratory, Washington, D. C.; Ronald W. Crawford and John A. Bollinger, San Diego State College (SDSC); Alfred W. Ebeling, Bingham

1.—U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries, Biological Laboratory, La Jolla, California.

Oceanographic Collection (BOC); John E. Fitch and John Radovich, California Department of Fish and Game; W. I. Follett and Lillian Dempster, California Academy of Science (CAS); John P. Harville, San Jose State College; Carl L. Hubbs and Richard H. Rosenblatt, Scripps Institution of Oceanography (SIO); Giles W. Mead, Harvard University Museum of Comparative Zoology (MCZ); George S. Myers and Hugh DeWitt, Stanford University Natural History Museum (SU); Leonard P. Schultz, U. S. National Museum (USNM); and Boyd W. Walker and Wayne J. Baldwin, University of California at Los Angeles (UCLA). We are indebted to Clifford L. Peterson (IATTC) for the data on which Fig. 11B is based. We are especially grateful to G. Palmer, British Museum (Natural History) for information on the type specimens of *Opisthonema libertate* and *O. bulleri*. Technical suggestions or comments on the manuscript that were of great value in analyzing and comprehending the data and in preparing this publication were made by Elbert H. Ahlstrom, Franklin G. Alverson, W. I. Follett, Jack W. Gehringer, Carl L. Hubbs, David Kramer, John S. MacGregor, Romeo Mansueti, Charles P. O'Connell, Clifford L. Peterson, Richard H. Rosenblatt, Milner B. Schaefer, and Stewart Springer. We thank Enrique L. Diaz for the translation into Spanish of this study.

INTRODUCTION

The thread herrings are marine fishes of the clupeid genus *Opisthonema* which occur only in the western Atlantic and Eastern Pacific Oceans, mainly in tropical and subtropical waters. They are characterized by a filamentous elongation of the last ray of the dorsal fin, a row of scutes along the ventral midline, scale rows crossing the back between the head and the dorsal fin, and an elliptical, thin-walled gizzard. The latter two characters distinguish the thread herrings from the gizzard shads (genus *Dorosoma*), which inhabit fresh waters of North and Central America and occasionally enter marine or estuarine coastal waters.

In the Pacific, before the abrupt change from the use of live-bait to purse-seining techniques in the tuna fishery (Schaefer, 1961), thread herring were important as a secondary bait fish (Schaefer, 1954). They were captured for this purpose from San Diego Bay, California, south to Peru and at the Galapagos Islands, where in certain areas and seasons the thread herring contributed substantially as a source of bait (Alverson and Shimada, 1957). In the Atlantic, thread herring are regarded as a potential supplemental source of fish for industrial uses. Experimental fishing for thread herring in the Gulf of Mexico and the prospects for the development of a commercial fishery were discussed by Butler (1961). Prior to the present study only two species were recognized: *Opisthonema oglinum* (LeSueur 1818) in the Atlantic and *Opisthonema libertate* (Günther 1866) in the Pacific. We have determined that a single species does occur in the Atlantic, but that four species exist in the Pacific.

Although a number of morphological characters were investigated, the separation of these species is essentially based upon differences in

complements of gillrakers. Because of the importance of gillrakers in the taxonomy of this genus and the possibility of similar importance in other groups, we have analyzed the ontogenetic and geographic variation in this structure and have presented a practical method for evaluating differences between species on the basis of this character.

TAXONOMY

Opisthonema Gill, 1861

Opisthonema Gill, 1861:37 (type species *Opisthonema thrissa* Gill, 1861 (*non* Linnaeus; = *Megalops oglina* LeSueur, 1818), by original designation).

Filialosa Fowler, 1944:207 (type species *Meletta libertatis* Günther, 1866, by original designation).

Characters.—Body laterally compressed, narrowing ventrad to a row of ventral scutes; ventral body profile more curved than dorsal; greatest depth usually between origins of dorsal and pelvic fins.

Head slightly rugose on top. Dendritic network of lateral line system on opercular bones and suborbital (also on scales just posterior to occiput and upper end of cleithrum). Snout moderately pointed; lower jaw slightly projecting (jaws nearly subequal). No distinct notch at premaxillary symphysis. Adipose eyelid present, dense and apical anteriad. Premaxillaries short, maxillaries making up most of gape; no supplementary bone between end of premaxillary and maxillary; two supramaxillaries, the anterior one smaller; posterior margin of upper jaw formed by ends of maxillary and posterodorsal supramaxillary, rounded, extending to below anterior part of pupil, greatest depth of margin usually larger than diameter of pupil. Jaws toothless in juveniles and adults (below about 30 mm S.L. symphyseal teeth present on dentaries and marginal teeth on maxillaries); a few thin recurved canines on floor of mouth just anterior to esophageal opening, but none on palate.

Operculum and preoperculum relatively elongated dorsoventrally and narrow anteroposteriorly. No marked bony striations on operculum. Branchiostegals 6, the last blunt, expanded distally, forming nearly a 90° angle with ventral margin of subopercle.

A weak bilobed dermal fold on anterior vertical margin of cleithrum, and a larger, anteriorly directed fold on dorsal side of anterior end of cleithrum, with a furrow between fold and isthmus. Gill membranes united and overlapping isthmus anteriorly, left membrane overlapping that on right side. Pseudobranchia relatively large.

Gillrakers relatively long and slender, the number on the first arch increasing with growth (to about 120 mm S.L. in one species, to larger sizes or throughout life in others) by addition at the anterior ends of the upper and lower limbs; the greatest number of gillrakers on the first arch (up to 353), the numbers of gillrakers progressively decreasing on the second, third, and fourth arches; third and fourth arches with rows of

gillrakers on both lateral and medial sides; the rakers on the lower limb near the angle not lying over those of upper limb, but lying lateral to them on larger specimens of species with a high number of gillrakers; most rakers of normal lanceolate shape, but some, especially on upper limb of large specimens, expanded laterally.

Ventral body midline formed of hardened scutes with posteriorly directed spines, extending from throat to vent (17 to 19 prepelvic, 14 to 17 postpelvic; 32 to 35 total).

Scales cycloid with small scallops on posterior margin, covering body and extending onto caudal fin, absent on head; a low elevated row of scales along insertions of dorsal and anal fins; an elongated axillary scale extending about ⅔ length of pelvic fin along its dorsal margin, no pectoral axillary scale; deciduous scales covering bases of pectoral and pelvic fins; scale rows extending from ventral scutes, up side and across ridge on back in front of dorsal fin and across back posterior to dorsal fin; about 42 to 53 transverse rows of scales from occiput to caudal base.

Dorsal fin inserted about midway between tip of snout and caudal base (its origin nearer tip of snout); all rays segmented; first 5 rays unbranched, the remainder branched, the last ray branched to its base but its branches secondarily fused in larger specimens (17-22 dorsal rays). The dorsal fin with an anterior lobe produced by the 5th, 6th, and 7th rays (the lobe about 13-21% S. L.); the dorsal rays increasing in length from the minute first ray (missing in some specimens) through the 6th ray and decreasing in length from the 6th ray to the next to the last ray; next to the last ray about twice as long as ray preceding it, last ray thickened at base and produced as a long tapering filament that extends about to caudal base (filament length about 31-47% S. L.).

Anal fin long, low, and inserted well back on body; 1st ray usually unsegmented (and occasionally the 2nd), the remainder segmented (19-25 anal rays); 1st ray frequently minute, 2nd ray short, usually 3rd through 5th increasing and 6th through 10th decreasing in length, remaining rays equal or slightly increasing in length to about the last 3 rays, with these of increasing length and the last ray the longest in the fin; next to last ray only slightly thicker than preceding rays; last ray about twice as thick as next to last ray and branched to its base. The numbers of dorsal and anal rays appear to be positively correlated—specimens with higher numbers of dorsal rays tend to have higher numbers of anal rays—and there are usually two more anal rays than dorsal rays.

Caudal fin deeply forked with subequal pointed lobes (10+9 principal rays).

Pectoral fins pointed, 3rd and 4th rays the longest (about 15-22% S. L.); inserted low on side below posterior margin of operculum; all rays segmented; 1st ray unbranched, all others branched; 1st ray flattened and closely adpressed to 2nd ray (16-19 pectoral rays); a fleshly ridge and ventral indentation for reception of dorsal part of fin against body.

Pelvic fins pointed, the 2nd and 3rd rays the longest (7-12% S. L.); inserted just above ventral scutes, below about middle of dorsal fin insertion; all rays segmented; 1st ray flattened and closely adpressed to 2nd ray; 1st ray unbranched, remainder branched; usually 9 rays, rarely 8 rays on one or both sides.

Vertebrae 44-49.

Alimentary canal with esophagus opening into 2 bilateral, anterodorsally projecting pharyngeal pockets, stomach extending posteriad (for about 20% S. L.), curving back on itself, and ending in a elliptical and relatively thin-walled gizzard; intestine extending posteriad (for about 30% S. L.), doubling back on itself to about end of gizzard, then recurving again and extending straight to vent. A small group of pyloric caeca at the front of the intestine enlarging into a mass of numerous caeca lying dextral to the intestinal folds. A pneumatic duct connecting gas bladder with posterodorsal part of stomach.

Pigmentation intraspecifically variable in preserved specimens. The following features occur in all species, but the presence of the last four on a single specimen is rare: 1) Dorsal surface dark about one-third to one-half way down the sides grading into silvery sides and ventral margin. 2) Dorsal fin with dark margin and filament, grading to a dusky or clear basal portion; caudal fin dusky with a dark stripe in each lobe extending from base to tip; pectoral fins with a dusky dorsal margin; anal and pelvic fins clear. 3) A fairly large opercular spot, rounded or usually vertically elongated, usually larger than pupil diameter. 4) One to several irregular rows of a variable number of smaller spots on the dorsolateral body surface, these beginning just posterior to the opercular spot and usually extending to below or beyond the position of the dorsal fin insertion. 5) A pair of dorsal spots, one on each side of and just posterior to the origin of the dorsal fin. 6) Two to six stripes on the dorsolateral body surface extending nearly to the peduncle.

Generic synonymy.—The genus *Filialosa,* proposed by Fowler in 1944, has been ignored by subsequent authors and is a synonym of *Opisthonema.* None of the characters Fowler proposed to distinguish *Filialosa* in the Eastern Pacific from *Opisthonema,* which he restricted to the western Atlantic, is of generic status; rather, the characters reflect interspecific differences and intraspecific variation. Fowler stated that the Pacific form had a less arched ventral profile, slightly longer head, smaller eye, maxillary less inclined, gill opening extending farther forward, dorsal fin origin farther posteriad, fewer dorsal and anal rays, longer last dorsal ray, and longer pectoral fins than the Atlantic form, and rows of dark spots on the sides of the body.

In creating the genus *Opisthonema,* Gill (1861:37) gave the following:

1) *Clupanodon* Lacépède, in part [as a synonym of *Opisthonema*].
2) *Opisthonema thrissa* Gill [as the type of *Opisthonema*].
3) *Clupanodon thrissa* Lacépède [as a synonym of *Opisthonema thrissa*].

Because Gill's apparent intent was to restrict *Opisthonema* to the western Atlantic, as opposed to Lacépède's and earlier authors' reference to a combination of Chinese and Atlantic forms, the type species must stand as *Opisthonema thrissa* Gill (*non* Linnaeus, 1758 = *Megalops oglina* LeSueur, 1818). This is essentially how Jordan (1919:303) recorded the type species.

Opisthonema medirastre new species (Fig. 1A)

Clupea (Opisthonema) Bulleri (*non* Regan), Regan, 1904:255 (in part; the 110-mm S. L. larger specimen collected with lectotype of *O. bulleri*).

Opisthonema libertate (*non* Günther), Radovich, 1961:27 (listed as "Pacific thread herring"; in part, only the specimen from Los Angeles Harbor, California, 21 Dec. 1958).

Diagnosis.—Ceratobranchial gillrakers increasing in number with increase in body length up to about 170 to 200 mm S. L.; ceratobranchial gillrakers at 200 mm S. L., 50 to 69 (increase in numbers of ceratobranchial gillrakers with standard length shown in Table 3 and Figs. 7, 8, and 9, and geographic variation shown in Fig. 10B). Range, in coastal, inshore waters of the Eastern Pacific from Peru to Los Angeles, California (Fig. 2A).

Description of the holotype [measurements in mm (% S. L. in parentheses)].—Standard length 175. Fork length 187 (106.9). Total length 219 (125.1). Head length, to cleithrum 41.1 (23.5), to distal margin of operculum 43.8 (25.0). Upper jaw length 17.4 (9.9). Maxillary depth 6.6 (3.8). Interorbital width 10.4 (5.9). Eye diameter 11.8 (6.7). Snout length 12.0 (6.9). Postorbital head length, horizontal 18.1 (10.3), maximum 23.7 (13.5). Body depth, vertical from dorsal fin origin 55.5 (31.7), origin of dorsal fin to origin of pelvic fin 56.5 (32.3), vertical of anal fin origin 37.9 (21.7). Peduncle depth least 15.1 (8.6). Body width, at postcleithrum 23.3 (13.3), at dorsal fin origin 27.9 (15.9). Peduncle width at least depth 5.7 (3.3). Snout to dorsal fin origin 77.5 (44.3). Snout to pectoral fin origin 43.7 (25.0). Snout to pelvic fin origin 91 (52.0). Snout to anal fin origin 136 (77.7). Pectoral fin origin to pelvic fin origin 48 (27.4). Pelvic fin origin to anal fin origin 48 (27.4). Dorsal fin lobe length 27.7 (15.8). Last dorsal ray length 69.5 (39.7). Dorsal base length 27.6 (15.8). Anal base length 27.6 (15.8). Pectoral fin length 32.3 (18.5). Pelvic fin length 17.0 (9.7). Dorsal rays 20. Anal rays 21. Pectoral rays 18 right, 17 left. Pelvic rays 9 left, 8 right. Scale rows, lateral about 49 left and 50 right, head to dorsal fin origin about 26, end of dorsal fin to caudal base on back about 26, dorsal fin origin to ventral midline about 16. Scutes 18+16. Ceratobranchial gillrakers 59.

Description of the species.—Represented in the following accounts, tables, and figures.

Holotype.—USNM 196804. Collected at Chorrera Bay, Gulf of Panama, 21-25 Aug. 1960, purse seine, by Inter-American Tropical Tuna Commission.

Paratypes.—Many specimens in the collections of many institutions.

Range and distribution.—From Sechura Bay, Peru, to Los Angeles Harbor, California (Fig. 2A). In Peru this may be the most abundant of the three Pacific coastal species, but elsewhere it is second to *libertate.* The only specimen from California available for examination was a 192-mm S. L. *medirastre,* although a number of specimens of *Opisthonema* apparently have been reported from California waters (Barnhart, 1936; Radovich, 1960).

Size.—Smallest and largest specimens examined, 30.0 and 220 mm S.L.

Synonymy.—Because the existence of this species has not been recognized previously, any unsubstantiated record of *libertate* from coastal waters of the Eastern Pacific may apply to it.

Derivation of the name.—From the Latin *medius,* middle or midst; and *rastrum,* a toothed hoe or rake; because this species has a number of gillrakers intermediate to those of the other two Pacific coastal species.

Common name.—Middling thread herring (new name).

Opisthonema berlangai new species (Fig. 1B)

Opisthonema libertate (*non* Günther), Gilbert, 1891:449 (in part; specimens from Indefatigable (Santa Cruz) and Chatham (San Cristobal) Islands, Galapagos, only: "This seems to be the species listed by Jordan and Bollman as *'Clupea* sp. (very young)' "). Herre, 1936:32 (small specimens from Eden Island, Galapagos). Fowler, 1938:20 and 249 (in part; Galapagos specimens only). Hildebrand, 1946:81 (in part; Galapagos reference only). Peterson, 1956:173 (in part; Galapagos reference only).

Clupanodon libertatis (*non* Günther), Snodgrass and Heller, 1905:348 (in part; specimens from Seymour (Baltra) Island and Wreck Bay of Chatham (San Cristóbal) Island, Galapagos, only).

Opisthonema libertatis (*non* Günther), Regan, 1917b:386 (in part; Galapagos reference only). Fowler, 1932:3 (specimens from Conway Bay, Indefatigable (Santa Cruz) Island, Galapagos).

Filialosa libertate (*non* Günther), Fowler, 1944:209 and 482, fig. 31 (in part; descr.; reference to Galapagos only).

Diagnosis.—Ceratobranchial gillrakers increasing in number with increase in body length up to about 260 mm S. L.; ceratobranchial gillrakers at 200 mm S. L., 63 to 84, increasing to about 68-87 at 260 mm S. L. (increase in number of ceratobranchial gillrakers with standard length shown in Table 3 and Fig. 12). Range, confined to vicinity of Galapagos Islands (Fig. 2A).

Description of the holotype [measurements in mm (% S. L. in parentheses)].—Standard length 173. Fork length 183 (105.8). Total length 210 (121.4). Head length, to cleithrum 41.9 (24.2), to distal margin of operculum 44.8 (25.9). Upper jaw length 17.7 (10.2). Maxillary depth 6.8 (3.9). Interorbital width 10.4 (6.0). Eye diameter 10.7 (6.2). Snout length

13.2 (7.6). Postorbital head length, horizontal 20.3 (11.7), maximum 25.5 (14.7). Body depth, vertical from dorsal fin origin 50.5 (29.2), origin of dorsal fin to origin of pelvic fin 51.7 (29.9), vertical of anal fin origin 35.7 (20.6). Peduncle depth least 15.2 (8.8), body width at postcleithrum 22.1 (12.8), at dorsal fin origin 22.0 (12.7). Peduncle width at least depth 6.3 (3.6). Snout to dorsal fin origin 75 (43.4). Snout to pectoral fin origin 43.3 (25.0). Snout to pelvic fin origin 83.5 (48.3). Snout to anal fin origin 129 (74.6). Pectoral fin origin to pelvic fin origin 43.6 (25.2). Pelvic fin origin to anal fin origin 47.2 (27.3). Dorsal fin lobe length 29.3 (16.9). Last dorsal ray length 69.5 (40.2). Dorsal base length 28.6 (16.5). Anal base length 27.0 (15.6). Pectoral fin length 30.2 (17.5). Pelvic fin length 15.9 (9.2). Dorsal rays 20. Anal rays 21. Pectoral rays 17 each fin. Pelvic rays 9 left, 8 right. Scale rows, lateral about 50 both sides, head to dorsal fin origin about 21, end of dorsal fin to caudal base on back about 28, dorsal fin origin to ventral midline about 15. Scutes 18 + 17. Ceratobranchial gillrakers 61.

Description of the species.—Represented in the following accounts, tables, and figures.

Holotype.—USNM 196807 (originally UCLA W55-314). Collected at east end of bay on northeast corner of Barrington (Santa Fe) Island, Galapagos Islands, 26 November 1955, rotenone poisoning by A. W. Ebeling and party.

Paratypes.—Many specimens in the collections of many institutions.

Range and distribution.—Restricted to the vicinity of Galapagos Islands, and the only species of *Opisthonema* known to occur at the Galapagos. Definite records are known from nine of the Islands (Fig. 2A). The most distant record is a specimen from about 70 miles northeast of the Galapagos. We examined specimens obtained from the Galapagos Islands as early as 1872 obviating the theory of their establishment there after being released as bait from tuna fishing boats (as has been suggested for some of the "bait" species).

Size.—Smallest and largest specimens examined, 23.0 and 260 mm S. L. The largest specimen of *Opisthonema* examined, 281 mm S. L., 80 ceratobranchial gillrakers, CAS, obtained from Steinhart Aquarium, collection locality unknown, is probably this species.

Synonymy.—Because this species is confined to the Galapagos and apparently is the only *Opisthonema* occurring there, it is presumed that all previous records of *libertate* from the Galapagos apply to *berlangai.*

Derivation of the name.—Patronymic for Fray Tomás de Berlanga, who is credited with the discovery of the Galapagos Islands in May 1535 (Slevin, 1959:13).

Common name.—Galapagos thread herring (new name).

Opisthonema libertate (Günther, 1866) (Fig. 1C)

Meletta libertatis Günther, 1866:603 (type locality La Libertad, El

Salvador; holotype in British Museum (Natural History), no. 1864.1. 26.181).

Clupea libertatis, Günther, 1868a:487 (listed; "closely allied to *C. thrissa")*. Günther, 1868b:433 (original descr. repeated).

Opisthonema libertate, Jordan and Gilbert, 1883b:622 (Pacific Panama specimens). Jordan, 1885:366 (listed from Mazatlan, Mexico, and Pacific Panama). Jordan, 1887b:825 (listed in tropical fauna of the Pacific coast). Gilbert, 1891:449 (in part; excluding specimens from Galapagos). Jordan, *et. al.,* 1895:408 (Sinaloa, Mexico, specimens). Jordan and Evermann, 1896:433 (descr.; range). Gilbert and Starks, 1904:40 (descr.; Panama specimens; *O. oglinum* mentioned). Osburn and Nichols, 1916:149 (Ballenas Bay and Carmen Island, Mexico, specimens). Meek and Hildebrand, 1923:188 (descr.; Chame Point, Taboga Island, and Panama Market, Pacific Panama). Jordan, Evermann, and Clark, 1930:44 (in check list). Breder, 1936:53 (specimens from Pedro Gonzales Island, Perlas Islands). Barnhart, 1936:15, fig. 46 ("seldom seen in San Diego"). Fowler, 1938:20 and 249 (in part; excluding Galapagos reference). Chapman, 1944:6, figs. 5, 10, 12, 15, and 18 (osteology). Nichols and Murphy, 1944:233 (small specimens from La Plata Island, Ecuador, and Gorgona Island, Colombia). Hildebrand, 1946:81 (in part; descr.; La Plata Island, Ecuador, and Sechura Bay, Peru; excluding Galapagos reference). Villagomez, 1948:51 (specimens from Manta, Manabi, Ecuador). Fitch, 1948:134, fig. 51 (specimen from San Pedro, California; abundant in Gulf of California; possible dispersal by tuna bait boats). Clothier, 1950:37, pl. II (osteology; San Pedro and Seal Beach, California). McHugh and Fitch, 1951:493 (range; San Pedro, California; Ballenas Bay, San Juanico Bay, Santa Maria Bay, and Magdalena Bay, Baja California, Mexico). Bini and Tortonese, 1955:159 (specimens from Chimbote and Mancora, Peru). Peterson, 1956:178 (in part; descr.; Gulf of Nicoya, Costa Rica, excluding Galapagos reference). Berdegué A., 1956:153, fig. 133 (descr.; listed for Pacific Mexico). Morrow, 1957:14 (specimens from Cabo Blanco and Talara, Peru). Harder, 1958a:370, fig. 5a, and 1958b:18, fig. 27 (digestive tract and pneumatic duct). Radovich, 1960:163 (off Belmont Pier, south of Long Beach, California). Fausto, 1961:1, fig. 1 (digestive tract after Harder 1958a: 370). Radovich, 1961:18 (listed), p. 27 (as Pacific thread herring; in part; specimen from Belmont Pier, Long Beach, California, 29 May 1958; excluding Los Angeles Harbor specimen which is *O. medirastre*), p. 31 (as Pacific thread herring; specimen from Redondo Beach, California, 9 Nov. 1959).

Opisthonema libertatis, Evermann and Jenkins, 1891:127 and 134 (Guaymas, Sonora, Mexico; *O. oglinum* mentioned). Regan, 1917b:386 (in part; descr.; excluding *C. (O.) bulleri* from synonymy and Galapagos reference). Hildebrand, 1925:283 (specimens from El Triunfo, El Salvador).

Clupanodon libertatis, Snodgrass and Heller, 1905:348 (in part; excluding Galapagos specimens).

Filialosa libertate, Fowler, 1944:209 and 482 (in part; descr.; Playa Muerto, Panama; excluding references to Galapagos material).

Diagnosis.—Ceratobranchial gillrakers increasing in number with increase in body length to sizes larger than 200 mm S. L.; ceratobranchial gillrakers at 200 mm S. L., 79 to 110 (increase in the numbers of ceratobranchial gillrakers with standard length shown in Table 3 and Figs. 7, 8, and 9, and geographic variation shown in Fig. 10A). Range, in coastal inshore waters of the Eastern Pacific from Peru to Mexico (Fig. 2A).

Description of the holotype [measurements in mm (% S. L. in parentheses)].—Standard length 54.4. Head length to distal margin of operculum 13.8 (25.4). Body depth vertical through dorsal fin origin 14.5 (26.7). Last dorsal ray length 18 (33.1). Pectoral fin length 8.3 (15.3). Pelvic fin length 5.5 (10.1). Gillrakers, epibranchial 41, ceratobranchial 34, hypobranchial 36, all on right side.

Description of the species.—Represented in the following accounts, tables, and figures.

Holotype.—BMNH 1864.1.26.181. Collected at La Libertad, El Salvador, by Salvin and Dow.

Range and distribution.—From between Pta. Sal and Pta. Picos, Peru, to Santa Rosalita Bay, Pacific coast of Baja California, Mexico (Fig. 2A). This is the most abundant of the three Pacific coastal species of *Opisthonema,* and numerous records have been obtained for Panama Bay, the Gulf of Nicoya, and Magdalena Bay.

Size.—Smallest and largest specimens examined, 21.0 and 215 mm. S. L.

Synonymy.—Except for specific references to the type specimen, all references to *libertate* must be questioned because they might apply to any of the three Pacific coastal species, unless the specimens referred to have been re-examined with knowledge of the three species.

Derivation of the name.—Named for La Libertad, port of El Salvador, the type locality.

Common name.—Deepbodied thread herring (changed from Pacific thread herring).

Opisthonema bulleri (Regan, 1904) (Fig. 1D)

Clupea (*Opisthonema*) *Bulleri* Regan, 1904:255 (in part; type locality Las Peñas (Puerto Vallarta), Jalisco, Mexico; lectotype 77 mm S.L. in British Museum (Natural History) no. 1892.9.5.131; not including a prior cotype 110 mm S. L., which is *O. medirastre*).
Opisthonema libertatis (*non* Günther), Regan, 1917b:386 (in part; synonymy reference to *bulleri* only.)

Lectotype designation.—Of the two specimens, 77 and 110 mm S. L., originally labeled as cotypes of *bulleri* by Regan, the smaller specimen,

77 mm, is herein designated as the lectotype of *bulleri*. The larger specimen, 110 mm, is *Opisthonema medirastre* (with 40 ceratobranchial gillrakers).

Diagnosis.—Ceratobranchial gillrakers increasing in number with increase in body length up to about 140 to 170 mm S. L.; ceratobranchial gillrakers from 170 to 200 mm S. L., 26 to 36 (increase in numbers of ceratobranchial gillrakers with standard length shown in Table 3 and Figs. 7, 8, and 9, and the slight indication of geographic variation shown in Fig. 10C). Range, in coastal, inshore waters of the Eastern Pacific from Peru into Mexico (Fig. 2A).

Description of the lectotype.—Standard length 77 mm. Ceratobranchial gillrakers 25.

Description of the species.—Represented in the following accounts, tables, and figures.

Lectotype.—BMNH 1892.9.5.131. Collected at Las Peñas (Puerto Vallarta), Jalisco, Mexico, by Dr. Buller.

Range and distribution.—From between Pta. Sal and Pta. Picos, Peru, to Mazatlan, Sinaloa, Mexico (Fig. 2A). Apparently the least abundant of the three Pacific coastal species; our largest collections are from Panama Bay and the Gulf of Tehuantepec.

Size.—Smallest and largest specimens examined, 54.5 and 196 mm S.L.

Synonymy.—When describing *bulleri,* Regan (1904:355) apparently overlooked the then well-known *libertate* of Günther, for he did not compare *bulleri* with that species, but did give a terse (and inaccurate) comparison of *bulleri* with the Atlantic species *Clupea thrissa* [= *O. oglinum*]. Regan's original description of *bulleri,* as *"Clupea (Opisthonema) Bulleri",* has been overlooked in subsequent ichthylogical faunal lists and synonymies, with one exception. It appears listed as a synonym of *Opisthonema libertatis* (*sic*), without any explanation, in one of Regan's later clupeid revisions (1917b:386).

Derivation of the name.—Patronymic for the collector, Dr. Buller.

Common name.—Slender thread herring (new name).

Opisthonema oglinum (LeSueur, 1818)

Clupea thrissa (*non* Linnaeus), Linnaeus, 1758:318 (in part; reference to Browne only). Broussonet, 1782: ? (in part; reference to Atlantic material only). Günther, 1868:432 (in part; excluding synonymy citations to Osbeck and Agassiz; descr.; specimens listed from Barbados, Dominica, Puerto Cabello, Trinidad, Granada, Santo Domingo, Cuba, Jamaica).

Megalops oglina LeSueur, 1818:359 (descr.; type locality Newport, Rhode Island; type specimen apparently not saved; *Clupea thrissa* of Bloch mentioned).

Megalops notata LeSueur, 1818:361 (descr.; type locality Pigeon, Guadalupe Island; type specimen not saved; *C. thrissa* of Bloch men-

tioned; characters of currently known intraspecific variation used to distinguish this specimen from that of *oglina* on p. 359 of same publication).

Chatoessus signifer DeKay, 1842:264, pl. 41, fig. 132 (type locality New York; type specimen, if originally preserved, would have subsequently been destroyed; *C. thrissa* of Bloch and *Megalops oglina* of LeSueur mentioned; common name given as "spotted thread herring"). Baird, 1855:349 (Great Egg Harbor Bay, New Jersey).

Meletta thrissa Valenciennes in Cuvier and Valenciennes, 1847:380 (descr.; type localities New York, Santo Domingo, Guadalupe, Martinique, and Brazil; related species names discussed). Bertin, 1940:277 (14 specimens in Paris Museum listed as paratypes and as synonym of *Opisthonema oglinum*).

?*Alausa striata* Valenciennes in Cuvier and Valenciennes, 1847:429 (descr.; type localities Guadalupe Island and Bahia, Brazil; said perhaps to be the same species as *Clupea arcuata* Jenyns). Storey, 1938:51 (Guadalupe types have apparently disappeared from Paris Museum, types from Bahia examined by Dr. Chabanaud, these are not in the genus *Harengula* as classed by Jordan and Evermann, 1896:431). Bertin, 1940:289 (2 specimens, 190 and 220 mm, from Bahia, listed as paratypes and synonymized with *Opisthonema oglinum*). Bertin, 1941:24 (elongated last ray of dorsal broken in the two type specimens).

Chatoessus eumorphus Gosse, 1851:290 (descr.; type locality Jamaica; type specimen aparently not saved).

Opisthonema thrissa (*non* Linnaeus), Gill, 1861:37 (designation of "*Opisthonema thrissa* Gill" as type species of new genus *Opisthonema*). Gill, 1873:33 (range and common names). Goode, 1877:293 (listed from Bermuda). Jordan and Gilbert, 1879:385 (specimens from Beaufort Harbor, North Carolina). Goode, 1879:119 (listed from east Florida). Bean, 1880:108 (specimen from eastern shore of Virginia). Goode and Bean, 1882:239 (listed from Gulf of Mexico). Jordan and Gilbert, 1882a:247 (specimens from Pensacola, Florida). Jordan and Gilbert, 1882b:268 (descr.; "the flesh said to be sometimes poisonous"). Jordan and Gilbert, 1883a:574 (note that *thrissa* had been referred to *Clupanodon* by Lacépède in 1803).

? *Opisthonema thrissa* (*non* Linnaeus), Goode and Bean, 1879:151 (a specimen 5½ inches long from Pensacola, Florida, USNM 21462, with D. 12 and A. 28; either counts or identity probably incorrect).

Opisthonemus thrissa (*non* Linnaeus), Poey, 1881:343 (Porto Rico; *fide* Evermann and Marsh, 1902:86).

Opisthonema oglina, Bean and Dresel, 1884:169 (specimens from Jamaica). Goode and Bean, 1885:195 and 206 (recognition of the Atlantic species of *Opisthonema*; restriction of *Clupea thrissa* Linnaeus to an Indo-Pacific species).

Opisthonema oglinum, Jordan 1886a:26 (listed from Beaufort, North Carolina). Jordan, 1886b:33 (collected at Havana, Cuba). Jordan,

1887a:561 (listed from West Indies). Jordan, 1887b:824 (listed for shore fauna of south Atlantic and Gulf states and the West Indies; note on restriction of *Clupea thrissa* Linnaeus). Jordan, 1890:645 (specimen from Port Castries, St. Lucia). Bean, 1891:93 (specimens from Cape Charles City, Virginia). Jordan, 1891:314 (specimens from Bahia, Brazil). Jordan and Evermann, 1896:432 (descr.; range). Evermann and Marsh, 1902:86 (descr.; San Juan Market, Palo Seco, Mayaguez; Guanica, Hucares, Isabel Segunda, Fajardo and San Geronimo, Porto Rico). Fowler, 1911a; (listed from Maryland and New Jersey). Fowler, 1911b: (specimens from New Jersey, Santo Domingo, Jamaica, Puerto Rico, Santa Cruz Is., and Brazil). Nichols, 1912:182 ("common in the Havana market," Cuba). Regan, 1917a:308 (reference). Regan, 1917b:385 (descr.; range). Nichols, 1921:22 (listed, Turk Islands, Bahamas). Meek and Hildebrand, 1923:187 (descr.; Mindi Cut, Colon Market, Fox Bay, and Porto Bello, Atlantic Panama). Hildebrand and Schroeder, 1928:101 (descr.; food, utilization; York River, Buckroe Beach, and Lynnhaven Roads, Virginia). Jordan, Evermann, and Clark, 1930:44 (in check list). MacCoy, 1931:21 (specimen from Chatham, Massachusetts). Breder, 1938:28 (listed, New York Harbor). Storey, 1938:12, fig. 5 (photograph of cleared and stained specimen from Sanibel, Florida). Fowler, 1941:134 (references from Brazil). Campos, 1942:191, pl. III, figs. 7, 8 (descr.; specimens from São Paulo, Ilha S. Sebastião, Rio de Janeiro, and Santos, Brazil). Fowler, 1944:434 and 457 (listed from Bahama Islands and Atlantic Panama). Fowler, 1945:164 and 266 (listing of specimens from South Carolina and Florida; synonymy containing several errors). Bigelow and Schroeder, 1953:112, fig. 49 (descr.; occurrence in the Gulf of Maine). Springer, 1957:169 (aggregation behavior; Content Key, Florida). Harder, 1958b:18, fig. 28 (digestive tract and pneumatic duct). Fausto, 1961:3, figs. 2-4 (digestive tract and pneumatic duct). Tabb and Manning, 1961:607 (records from northern Florida Bay, Florida).

Clupanodon oglinum, Fowler, 1906:102 (descr.; New Jersey).

Diagnosis.—Ceratobranchial gillrakers increasing in number with increase in body length up to about 120 mm S. L.; ceratobranchial gillrakers from 120 to 230 mm S. L., 29 to 47 (increase in numbers of ceratobranchial gillrakers with standard length shown in Table 3, this and geographic variation shown in Fig. 13). Range, throughout the western Atlantic from Brazil to the Gulf of Maine, in the West Indies and at Bermuda (Fig. 2B).

Description of the holotype.—The original description of LeSueur (1818:359).

Description of the species.—Represented in the following accounts, tables, and figures.

Holotype.—Collected at Newport, Rhode Island. Possibility of original preservation or subsequent deposition of the holotype unknown to us.

Range and distribution.—Known from the Gulf of Maine (MacCoy, 1931:21), at Bermuda, and throughout the West Indies, to Florianopolis, Ilho de Argentina, Santa Catarina, Brazil (southward extension of previously published range, Fig. 2B). The northernmost specimen examined is from Hampton Roads, Virginia.

Size.—Smallest and largest specimen examined, 41.6 and 233 mm S. L.

Synonymy.—The early use of the name *Clupea thrissa* Linnaeus for the Atlantic species of *Opisthonema* was promulgated by Linnaeus' reference to this name in a Jamaica record (1758:318) and to two specimens from Carolina (1766:524). Goode and Bean (1885:195 and 206) examined the Linnaean collection in London, stated the errors in Linnaeus' accounts, detailed the necessity for restricting the name *thrissa* to an Asian species, and recognized the *Megalops oglina* of LeSueur as the proper name for the Atlantic *Opisthonema*. Jordan (1887b:824) condensed and further clarified the issue. *Clupea thrissa* Linnaeus is now regarded as the type species of genus *Clupanodon* Lacépède 1803, a dorosomatid genus inhabiting coasts and rivers of China and Japan (Regan, 1917a:308).

Derivation of the name.—"Name unexplained, unless from the word *ogle,* in allusion of the large eyes" (Jordan and Evermann, 1896:432).

Common name.—Atlantic thread herring.

Opisthonema palosverdensis David, 1943 (fossil species)

Opisthonema palosverdensis was described as a new species by David (1943:84, fig. 14) from a specimen from a Miocene formation in the Palos Verdes Hills, Los Angeles County, California. The specimen (150+35=185 mm in length, No. 10101 Calif. Inst. Technol. Coll. Vert. Paleont.) can be associated with the Clupeidae primarily because of the scutes on the ventral midline. David's interpretation of the dorsal fin was used to associate the specimen with the genus *Opisthonema*: "last ray evidently produced to a long filament, visible in those regions where stone particles have not been broken off; ray pushed out of place and leans backwards, its base extending under base of preceding rays." If this interpretation is not correct, the fossil can hardly be identified with *Opisthonema*. If it is correct, the generic association with *Dorosoma* Rafinesque must also be considered. The long head and the long caudal fin of the line drawing of the specimen are unlike any recent species of either *Dorosoma* or *Opisthonema*. The posterior insertion of the pelvic fin (under posterior end of dorsal fin) and the large jaw structure depicted are more like *Opisthonema* than *Dorosoma*. Comparable meristic characters are:

	Fossil specimen	*Opisthonema*	*Dorosoma*
Dorsal rays	17	17-22	9-14
Anal rays	at least 25	19-25	22-38
Ventral scutes	17+12 to 14	17-19+14-17	15-20+9-14
Vertebrae	41 or 42	44-49	43-51

COMPARISON OF SPECIES

A combination of two features is used to separate the five species: 1) geographic distribution and 2) gillraker number in relation to fish length. Four species occur in the Eastern Pacific, with *berlangai* confined to the Galapagos Islands, and *libertate, medirastre,* and *bulleri* occurring sympatrically in coastal waters from Peru to Mexico (Fig. 2A); *oglinum* occurs in the western Atlantic (Fig. 2B). The species, listed in order of increasing gillraker complements, are *bulleri, oglinum, medirastre, berlangai,* and *libertate.* The three sympatric Pacific species can be separated from each other by this character. The gillraker complements of the geographically isolated *oglinum* and *berlangai* overlap those of the other species.

A large number of other characters was examined. Although some of these show mean or modal differences among species, all have some degree of intraspecific variation. In addition, the ranges of these characters for each species overlap (usually appreciably) the ranges of all other species. Because they are of limited value in separating the species, a thorough analysis of these characters is not presented. The range and mean values of eight meristic characters are given in Table 1 and the range of six morphometric characters is given in Table 2. Inspection of these tables will indicate the extent of overlap in values between species and the slight differences that occur in the mean values of meristic characters.

Before dismissing these characters, three observations should be noted. 1) Sexual dimorphism was apparent in three characters—some females tended to have slightly deeper bodies and shorter pectoral and pelvic fins than males from the same collection. 2) Geographic variation was negligible in meristic characters (with the exception of gillrakers), but was pronounced in two morphometric characters—specimens of *libertate* and *medirastre* from Mexico have shorter heads and less deep bodies than those from Costa Rica and Panama. Morphometric trends of this nature were sumarized by Barlow (1961). 3) The relation of the number of gillrakers is the converse of what might be expected, in view of the generalization that the number of meristic elements is progressively greater from warmer to colder waters (discussed by Barlow, 1961). In *libertate* and *medirastre,* there are fewer gillrakers in the colder, northern areas than in the warmer, southern areas. We theorize for these species that while head length is dependent upon environmental conditions, the number of gillrakers is not; but rather that gillraker numbers are dependent upon head length—the shorter the head, the fewer the gillrakers. McHugh (1954:147) alluded to a similar relation in the Pacific herring.

Before discussing the relation of gillraker numbers to fish size, it is necesary to define the standard length measurement and to describe briefly the gillraker morphology.

Standard length measurement

Standard length is measured from tip of snout to end of medial hypural bones (caudal base). On smaller specimens (below 80 mm S. L.), the caudal base can be seen more readily with transmitted light. On larger specimens, the caudal base is obscured by muscle and connective tissue, and by scales extending onto the caudal fin. The frequently used technique of recording the location of the caudal base—the vertical line of flection that occurs when the caudal fin is bent to one side—does not apply to *Opisthonema*. The flection line occurs anterior to the caudal base in this genus (by about 1.5% S. L.), especially on larger fish. This probably occurs because the median caudal rays of both the dorsal and ventral lobes develop enlarged and elongated bases which overlie the median hypurals on each side and extend anteriad almost to the urostyle; the bases of the more dorsal and ventral principal rays also extend over the hypural bones. These extended ray bases give a rigidity to the tail that is reflected in a flection line more anterior than in many other fishes.

Gillraker morphology and counts

The first gill arch of a large specimen is illustrated in Fig. 3A; the ossified portions of the first gill arch in a small specimen are illustrated in Fig. 3B.

Epibranchial gillrakers and ceratobranchial gillrakers are easily differentiated at the angle between the upper and lower limbs in smaller specimens (to about 120 mm S. L.) because of the configuration of the bases of the rakers located at the junction (Fig. 3B). On larger specimens the junction is distended dorsolaterally with a consequent distortion of the bases of the rakers in this area, making the distinction more difficult.

A raker at the junction of the ceratobranchial and the hypobranchial segments is arbitrary designated as *ceratobranchial* when the major portion of its base is posterior to the line of junction and as *hypobranchial* when anterior to this line of junction. This line of junction is marked by a slightly oblique, distinct pigmented line in the middle of a narrow, relatively translucent area of tissue. The oblique line is variously colored cream, yellow, or orange, and appears to be composed of fatty tissue. The translucent tissue on either side of the line is composed of cartilage from the anterior end of the ceratobranchial and the posterior end of the hypobranchial bones (Fig. 4). This line can be seen readily on most preserved specimens, but on others, because of pigmentation or opaqueness, a portion of skin in the vicinity of the junction must be removed to reveal the line.

The relative sizes of different gillrakers and their relative positions on the gill arch are shown in Fig. 5. With continued growth of the fish some rakers form lateral expansions that may make gillraker counting difficult. These enlarged rakers are most numerous on the epibranchial segment, are more numerous in larger than in smaller specimens, and are more numerous in *libertate* than in the other species.

Bilateral variation is insignificant and may be disregarded.

Gillraker ontogeny

The number of gillrakers increases with increase in body length. This increase in number continues to an estimated 120 mm S. L. in *oglinum,* to between 140 and 170 mm S. L. in *bulleri,* and to over 200 mm S. L. in the other three species. After the initial formation of rakers on the three segments at about 20 mm S. L., rakers continue to form at, and only at, the anterior ends of the epibranchial and the hypobranchial segments, thus accounting for the increase in the number of rakers on these segments. However, the number of gillrakers also increases on the ceratobranchial segment. This occurs because the rakers are inserted not into the bones but loosely into the connective tissue overlying the bones. As the anterior end of the ceratobranchial bone grows anteriad, it pushes the hypobranchial bone forward in front of it, with the result that the anterior end of the ceratobranchial bone comes to lie under gillrakers that previously were over the posterior end of the hypobranchial bone.

The total numbers of gillrakers on the first arch in relation to standard length are shown in Fig. 6. The three Pacific coastal species can be separated by this character. For specimens larger than 150 mm S. L., *libertate* has the highest total number of gillrakers (about 290 to 353), *medirastre* has an intermediate number (about 180 to 256), and *bulleri* has the lowest number (about 103 to 128); *berlangai* (about 215 to 284 rakers) overlaps the range of *medirastre* and at small sizes overlaps the range of *libertate; oglinum* (about 125 to 157 rakers) is intermediate between *medirastre* and *bulleri.*

The number of gillrakers on each of the three segments of the gill arch have the same interspecific relation to standard length as do the total number of gillrakers. The following approximate ranges of epibranchial, ceratobranchial, and hypobranchial gillrakers apply to specimens larger than 150 mm S. L.:

	epibranchial	ceratobranchial	hypobranchial
libertate	110-149	71-107	90-117
medirastre	70-99	50-68	60-88
bulleri	35-47	28-35	37-48
berlangai	75-117	58-80	75-91
oglinum	43-60	30-46	42-61

Ceratobranchial gillraker analysis

The numbers of ceratobranchial gillrakers completely separate the three sympatric Pacific coastal species and are the preferable criterion of interspecific differentiation for three reasons: 1) they are relatively few, a maximum of 107 ceratobranchial compared to the maximum of 359 total gillrakers; 2) the anterior rakers on the epibranchial and hypobranchial segments are small and somewhat indistinct; 3) the entire ceratobranchial portion is made visible simply by raising the operculum.

Adequate assessment of gillraker variation requires for each species: a large number of specimens (to account for intraspecific variation), a

complete size series of specimens (for ontogenetic variation), and specimens from the throughout the entire area of occurrence (for geographic variation). The collections available to us have approached these requirements.

We have determined for the four widespread species (*libertate, medirastre, bulleri,* and *oglinum*) that geographic variation occurs in the relation between the number of gillrakers and the standard length.

The first concern in distinguishing the species is the separation of the three that co-exist in Eastern Pacific coastal waters. The other two species, geographically isolated from these and from each other, can then be compared.

The relations between the number of ceratobranchial gillrakers and the standard length are plotted in Fig. 7 for all specimens of *libertate, medirastre,* and *bulleri* from Peru, Panama, and Costa Rica (including one specimen of *libertate* from Colombia and three from El Salvador). All specimens of *bulleri,* with the low number of gillrakers, can be easily distinguished, as can the larger specimens of *libertate* and *medirastre* (greater than about 90 mm S. L.). The overlap in the profiles (see page 132) for the small specimens of *libertate* and *medirastre* results from the inclusion in this one figure of specimens from different areas. Small specimens (less than 60 mm S. L.) of *medirastre,* and possibly of *libertate,* from Peru tend to have more ceratobranchial gillrakers, on the average, than do small specimens of these species from Panama. Small specimens of *medirastre* and *libertate* from Costa Rica have, on the average, fewer ceratobranchial gillrakers than do those from Panama. Consequently, in regard to these small specimens, *medirastre* from Peru has gillraker complements similar to those of *libertate* from Costa Rica.

In all five species the number of gillrakers increases with increase in body length, up to maximum values that are interspecifically different, as previously noted. Each species has a different and distinctive pattern of increase in the number of gillrakers with increase in standard length. The increase in the number of gillrakers could be expressed as a curvilinear regression of number on size, but this line would not be as pertinent as the variation about it. The latter permits one to know what ranges in numbers of gillrakers may be expected at different lengths in the five species.

Calculation of confidence limits for the regressions would be difficult, because 1) the relation is curvilinear and 2) the variation in the number of ceratobranchial gillrakers increases with increasing length. The most practical technique is to plot the number of ceratobranchial gillrakers against the standard length and to enclose these points with a continuous line about their perimeter. This perimetric line is termed, for the purposes of the present study, the ceratobranchial gillraker *profile* and represents the pattern of increase in the number of ceratobranchial gillrakers with increasing standard length. The profiles are characteristic for each species,

although, as noted later, the separations between species are not complete for smaller sizes.

The number of ceratobranchial gillrakers is plotted against standard length in Fig. 8 for all specimens of *libertate, medirastre,* and *bulleri* from southern Mexico (Chiapas to Nayarit) and southeastern Baja California (Cape San Lucas to Concepción Bay).

The number of ceratobranchial gillrakers is plotted against standard length in Fig. 9 for all specimens of *libertate, medirastre,* and *bulleri* from the northern mainland of Mexico (Sinaloa and Sonora), northeastern Baja California (San Luis Gonzaga Bay to San Felipe), and western Baja California (from Almejas Bay northward, including a single specimen of *medirastre* from Los Angeles, California).

For convenience, the geographical areas considered in Fig. 8 will be refered to in the text and in the figures as southern Mexico and those in Fig. 9 as northern Mexico. The separation of these two areas is not intended to suggest a strict zoogeographical discontinuity between them or an environmental similarity within each. However, the relations between the number of ceratobranchial gillrakers and standard length are generally similar within the areas, and geographical variation is evident between the areas. Adequate numbers of specimens of all sizes of all species from all areas of Mexico would probably reveal a cline in decreasing numbers of gillrakers from South to North, with the specimens from southeastern Baja California having, on the average, a slightly greater number of gillrakers than specimens from their latitudinal equivalent on the mainland (Sonora).

The overlap in ranges of gillraker counts of small specimens of *bulleri* and *medirastre* in Fig. 8 occurs because small specimens of *bulleri* from the Gulf of Tehuantepec were plotted with small *medirastre* from Banderas Bay to the north. Intraspecifically the more southerly Tehuantepec specimens have, on the average, slightly higher numbers of gillrakers than those from Banderas Bay. Plotting small specimens from more restricted geographic areas tends to eliminate this overlap, as will be shown later.

The geographical variation in the numbers of gillrakers is illustrated separately for each species in Fig. 10 (A, B, and C) by superimposing the profiles for each area.

For *libertate* (Fig. 10A), the lower limits for the range from each area show a cline of South to North decrease in the number of gillrakers. There is less consistency in the upper limits of the profiles for larger sizes in that the upper limit of the group from northern Mexico is higher than that of the southern Mexico group. This is probably an artifact caused by the unequal sample size of these two groups. The profile for the southern Mexico group was estimated from only ten specimens larger than 140 mm S. L., and probably does not represent the true extent of variation at the larger sizes. The profile for the northern Mexico group is based on a greater number of the larger specimens with relatively great variation.

This included one collection of 93 specimens, 167 to 200 mm S. L., from the northern Gulf of California. In two of these specimens the number of ceratobranchial gillrakers was 82 at 197 mm and 106 at 200 mm.

For *medirastre* (Fig. 10B), the cline in South to North decrease is readily apparent. The profile for the Peru-Panama-Costa Rica group becomes asymptotic at the larger sizes, indicating no further increase in the numbers of ceratobranchial gillrakers after about 180 mm S. L. In the two groups from Mexico, the number of ceratobranchial rakers apparently continues to increase beyond a standard length of 180 mm.

For *bulleri* (Fig. 10C), a species with a relatively low complement of gillrakers, a geographical cline in numbers of rakers is not apparent. However, the profile for the larger specimens from Mexico is based on only five specimens, and such a cline may exist.

The profiles for each species from all areas were combined and are presented as a single profile for each species in Fig. 10D. These profiles include the maximum and minimum value for each species. They show, of course, more overlapping (especially at smaller sizes) between the species than do the geographically differentiated profiles. The distinctive profile for each species represents the specific pattern of increase in the numbers of ceratobranchial gillrakers for that species. This pattern characterizes that species.

Fig. 11A is an illustration of the intraspecific variation and the yet discrete interspecific separation of small specimens from the same area. It is based on a single collection from Sonora, Mexico (UCLA, W50-40) that contained 196 specimens of *Opisthonema* representing two species:

medirastre, 109 specimens, range 45.0-70.5 mm, mean 59.9 mm.

libertate, 87 specimens, range 45.0-64.0 mm, mean 53.8 mm.

At these smaller sizes the total intraspecific variation is less than at larger sizes, but the extent of separation between species is also less.

A situation similar to that for the Sonora collection is presented in Fig. 11B for 537 specimens from 19 collections made in the Gulf of Nicoya, Costa Rica, from 1952-1960, representing three species:

libertate, 412 specimens, range 21.0-85.0 mm.

medirastre, 142 specimens, range 30.0-65.0 mm.

bulleri, 3 specimens, range 30.0-86.0 mm.

Positive separation of *libertate* and *medirastre* may be made down to about 35 mm S. L.; below this, separation is less definite. The specimens of *bulleri* are readily separable.

For *berlangai,* the isolated Galapagos species, the numbers of ceratobranchial gillrakers are plotted against the standard length in Fig. 12; the profiles for the three Pacific coastal species (taken from Fig. 10D) are also indicated. The profile for *berlangai* is quite different from those of the other three species; at smaller sizes there is more of an overlap with *libertate,* at intermediate sizes the major overlap is with *medirastre,* and at the larger sizes it fills the gap between these two species.

For *oglinum*, the widely distributed western Atlantic species, the numbers of ceratobranchial gillrakers are plotted against standard length in Fig. 13; profiles of the three Pacific coastal species (taken from Fig. 10D) are also indicated. The profile for *oglinum* is markedly different from the other three species. It overlaps that for *libertate* for sizes up to about 100 mm S. L., that for *medirastre* up to about 170 mm, and that for *bulleri* after about 60 mm; it also fills the gap between *medirastre* and *bulleri*. The most striking characteristic of the profile of *oglinum* is the relatively small body size at which it becomes asymptotic. Some geographic variation exists in *oglinum,* and four different geographical groups are distinguished in Fig. 13. Specimens of *oglinum* from coastal waters of the United States, Mexico, British Guiana and Surinam, and Brazil, with generally similar ranges in numbers of gillrakers, are plotted together; this group has, on the average, the lowest numbers of gillrakers. The specimens of *oglinum* from the Atlantic coast of Panama are generally similar to specimens from insular waters (around Bermuda and the West Indies), and both these groups have, on the average, a higher number of ceratobranchial gillrakers than do specimens from the other areas. Despite gaps in the distributional representation of our samples of *oglinum,* the data are sufficient to show (in this and all other characters examined) that we are dealing with a single Atlantic species and that the speciation that has occurred in the Pacific has no counterpart in the Atlantic.

The distinctive profiles of the five species are compared in Fig. 14.

Key to the species

Three features are used in identifying specimens: location of capture, standard length, and number of ceratobranchial gillrakers. Because the gillraker-standard length relation is ontogenetically variable, a simple dichotomous key cannot be used. Table 3 serves as a key to species identification. For example, if a specimen from Panama has 35 ceratobranchial gillrakers and a standard length of 75 mm, it is *medirastre.* A specimen from northern Mexico with 29 ceratobranchial gillrakers at 120 mm S. L. is *bulleri.* Specimens from the Galapagos and from the Atlantic are presumed to be *berlangai* and *oglinum,* respectively.

There are overlaps of ranges of standard length at certain low numbers of ceratobranchial gillrakers—especially for *libertate* and *medirastre* from the southern areas. A specimen that fits in the zone of overlap must be identified by the comparison of a series of the two species in question from that particular locality. For examples of this positive identification of smaller specimens see Fig. 11.

Other studies on clupeoid gillrakers

A number of references deal with increase in gillraker number with increase in body length in clupeoid fishes. While none of these was directly pertinent to our study, they may be relevant to studies on other clupeoid species. Such studies include Bardán, Navarro, and Rodríguez (1949) on *Sardinia pilchardus;* Andreu (1953) on *Sardinia pilchardus;*

McHugh (1954) on *Clupea pallasi;* Montiero (1960) on *Sardinella eba;* Scofield (1934) on *Sardinops caerulea;* Sako (1938) on *Sardinops melanosticta;* Andreu (1955) on *Engraulis encrasicolus;* McHugh (1951) on *Engraulis mordax mordax;* de Plaza and Boschi (1958) on *Engraulis anchoita;* Howard (1954) on *Cetengraulis mysticetus;* and Peterson (1956) on *Anchovia macrolepidota* and *Anchoa starksi.*

Alimentary canal and food

There are no apparent differences in the external features of the alimentary canal among the four Pacific species. In these, all parts of the digestive tract have a similar diameter except for a wider, bulbous, muscular thickening of the distal portion of the stomach. In *oglinum* the diameters of the esophagus and stomach are greater than in the rest of the tract, and the distal portion of the stomach is bulbous and muscular as in the Pacific species. Brief descriptions of the alimentary canals by Harder (1958a and b) and Fausto (1961) are partially misleading.

Food and feeding habits will be investigated in detail in future studies of the biology of these species, because the appreciable interspecific differences in numbers of gillrakers suggest that some differences in food selection occur. Our examinations of stomach contents have been limited. In the specimens examined, there was little material in the stomach, and this was predominantly amorphous in appearance. In larger specimens of *bulleri* and *medirastre,* stomachs frequently contained numbers of crustaceans and pteropods, while in larger *libertate* the stomachs contained relatively smaller numbers and sizes of these organisms. In smaller specimens (100-120 mm S. L.), stomach contents of all three species were similar and mainly amorphous.

Species collected together

All three Pacific coastal species occurred together in six collections; *medirastre* and *bulleri* occurred together in three collections; *libertate* and *bulleri* in six collections; and *libertate* and *medirastre* in 22 collections. In 34 of these 37 multiple-species collections the sizes or size ranges of the species were nearly equal or overlapping. This does not necessarily imply that the different species were schooling together, as the collection methods could have sampled different schools in the same area. However, in a collection of *libertate* and *medirastre* from Banderas Bay, 21 Aug. 1961, both species were probably schooling together in the very small area enclosed by the seine.

Specimens examined

Our examinations were based on the following numbers of collections and specimens:

oglinum	63 collections	202 specimens
berlangai	34 collections	345 specimens
libertate	150 collections	1914 specimens
medirastre	63 collections	579 specimens
bulleri	22 collections	172 specimens

Specimens that were examined are in the collections of the institutions mentioned in the section on acknowledgements and at the U. S. Bureau of Commercial Fisheries, Biological Laboratory, La Jolla, California.

DISCUSSION

Prior to this study, the taxonomic status of *Opisthonema libertate* and *O. oglinum* was similar to that of the majority of the American geminate species (or species pairs or cognate species). It was recognized that similar pairs with disjunct distributions occurred in the western Atlantic and the Eastern Pacific, but no critical evaluation of these forms had been made, and they were designated somewhat randomly as distinct species, the same species, or (less frequently) subspecies.

Since the 1860's all writers have recorded *oglinum* and *libertate* as separate species. Usually three characters have been listed to separate the species: *libertate* with different pigmentation, a longer head, and more gillrakers than *oglinum*. Some writers have objected to one or more of the suggested distinctions (as Gilbert and Starks, 1904:40). No one has reported on detailed evaluations of these differences. It is generally recognized that the number of gillrakers increases with the increase in body length in certain species of clupeoids.

We have documented the differences in gillraker complements and disproved the discreteness of other reported differences between *oglinum* and *libertate* (*sensu stricto*). It is obvious that earlier writers who declared that the Pacific form had more gillrakers were probably basing their separations on only larger specimens of *libertate* (*sensu stricto*). We know now that there are four different forms in the Eastern Pacific, and that this complex is the previously recognized *libertate* (*sensu lato*).

There are possible relationships among these five forms of *Opisthonema* other than the necessarily subjective one we have used in designating them as five separate species. They might have been designated as subspecies or as polymorphic forms of one or more species. However, in consideration of a number of associated factors we believe that our view of the relationships is the most feasible.

Three distinct forms co-exist over a great latitudinal distance in coastal, inshore waters of the Eastern Pacific. Each of these is presumed to consist of a continuous population over its entire geographic range. To designate them as sympatric subspecies would be excessively speculative without detailed knowledge of ecological or microhabitat differences. To regard them as elements of a trimorphic race is without parallel in known species divergence of fishes in marine environments, and, although this is a possible explanation of the differences, it is not justifiable in the present system of morphological taxonomy based on the study of preserved specimens. It is unlikely that *medirastre,* with the intermediate number of gillrakers, is a hybrid, because mature specimens of all five forms have been examined, and mature specimens of the three sympatric species have been found in completely segregated collections of each form

as well as together. Based on our present knowledge, the three sympatric forms are best regarded as distinct species.

The single form of *Opisthonema* in the Atlantic has a distinctive gillraker profile discrete from those of the three Pacific coastal species, although it overlaps the profiles of these three species at different sizes. Because of its long-term isolation from these Pacific forms and because of the impossibility of assigning it definitely to a subspecific relationship with any one of these, the Atlantic form is logically considered to be a distinct species.

The single form of *Opisthonema* that occurs at the Galapagos Islands is classified as a distinct species. It is not considered as a subspecies of one of the Pacific coastal species, even though the gillraker profile overlaps those of *libertate* and *medirastre*. The greatest amount of such overlap is with *medirastre* from the Peru-Costa Rica area at sizes of about 120 to 160 mm S. L. and with *libertate* from the northern Mexico area at sizes of about 30 to 110 mm S. L.; it also has an appreciable amount of overlap with specimens of *oglinum* from the West Indies at about 50 to 80 mm S. L. If this overlap were indicative of a very close, *i.e.* subspecific, relationship, it should be at a maximum with smaller and less environmentally influenced sizes (less than about 80 to 100 mm S. L.), and with specimens from the area (Peru, Ecuador, and Panama) that would contribute recruitment to the Galapagos on the basis of oceanographic conditions. Such a combined condition does not exist. This reasoning and five other factors warrant the recognition of *berlangai* as a distinct species. 1) It has a gillraker profile that is distinct from all the other species. 2) It is the only species of *Opisthonema* that occurs at the Galapagos, while three species occur on the continental coast adjacent to the Islands. 3) It apparently is isolated from the coastal species over 500 miles away, for our data indicate that thread herrings in the Pacific do not range very far from their inshore habitats. 4) It is evidently a self-sustaining population (mature adults and very small juveniles have been examined). 5) The single form in the Atlantic, *oglinum,* is classified as a distinct species on the basis of similar reasoning (its geographic isolation and distinctive gillraker profile).

Speculation on the phylogenetic relationships of the five species of *Opisthonema* may vacillate in a number of directions. If a single species existed before the separation of the Atlantic and the Pacific by the emergence of the Isthmus of Panama the progenitor was probably either the *bulleri* type with a low number of gillrakers or a more variable and possibly more adaptable *oglinum* type. *O. medirastre* might have envolved from *bulleri* and *libertate* from *medirastre,* with *berlangai* developing from either of the latter.

FIGURE 1. A) *Opisthonema medirastre*, holotype, Chorrera Bay, Panama, 175 mm S. L. B) *Opisthonema berlangai*, holotype, Barrington Island (Santa Fe), Galapagos Islands, 173 mm S. L. C) *Opisthonema libertate*, Isla Verde, Panama, 162 mm S. L. D) *Opisthonema bulleri*, Isla Chepillo, Panama, 174 mm S. L.

FIGURA 1. A) *Opisthonema medirastre*, holotipo, Bahía Chorrera, Panamá, 175 mm de L. E. B) *Opisthonema berlangai*, holotipo, Isla Barrington (Santa Fe), Islas Galápagos, 173 mm de L. E. C) *Opisthonema libertate*, Isla Verde, Panamá, 162 mm de L. E. D) *Opisthonema bulleri*, Isla Chepillo, Panamá, 174 mm de L. E.

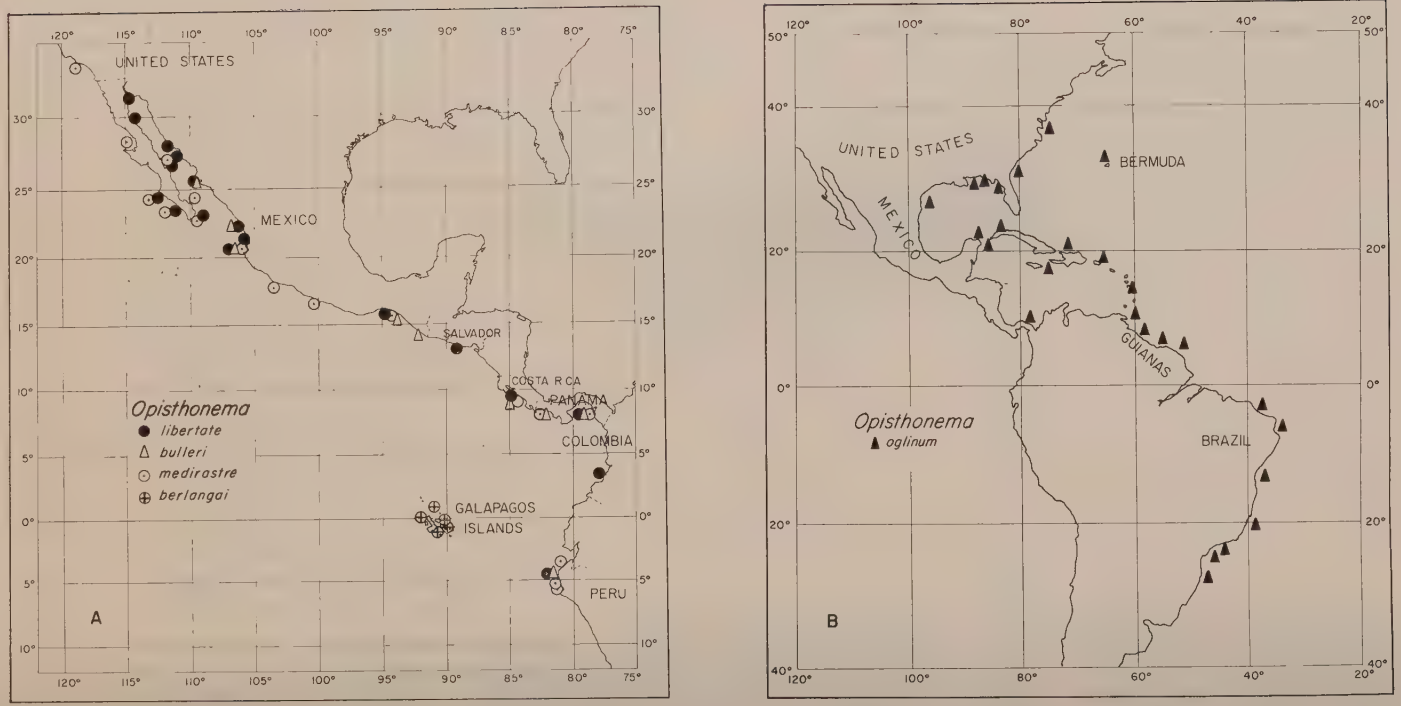


FIGURE 2. Areas from which collections were examined. A) *Opisthonema libertate, O. medirastre, O. bulleri,* and *O. berlangai.* B) *Opisthonema oglinum.* All collections are not shown when several occurred in the same general area.

FIGURA 2. Area de donde provinieron las recolecciones examinadas. A) *Opisthonema libertate, O. medirastre, O. bulleri* y *O. berlangai* B) *Opisthonema oglinum.* La totalidad de las recolecciones no aparecen cuando se tomaron varias en la misma área general.

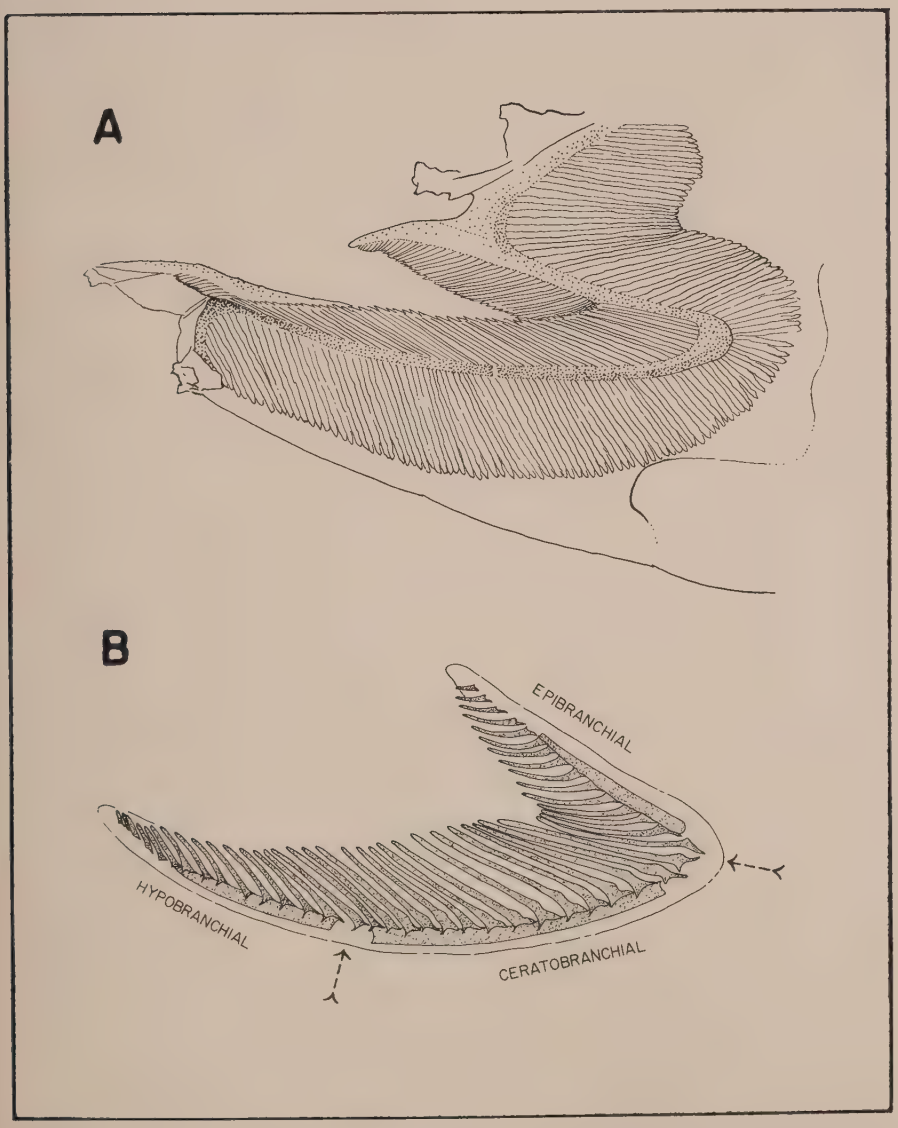


FIGURE 3. A) First gill arch of a 155 mm specimen of *Opisthonema libertate*. B) First gill arch (with gill filaments removed) of a 28.5 mm S. L. specimen of *Opisthonema berlangai*, cleared and stained to show ossification (stippled); the three branchial bones are ossified further anteriad and posteriad on larger specimens. Arrows indicate the cartilaginous junctions of the three bones.

FIGURA 3 A) Primer arco branquial de un espécimen de 155 mm de *Opisthonema libertate*. B) Primer arco branquial (se han removido los filamentos branquiales) de un espécimen de 28.5 mm de L. E. de *Opisthonema berlangai*, aclarado y teñido para mostrar la osificación (punteado); los tres huesos branquiales se osifican más anteriormente y posteriormente en ejemplares grandes; las flechas indican las uniones cartilaginosas de los tres huesos.

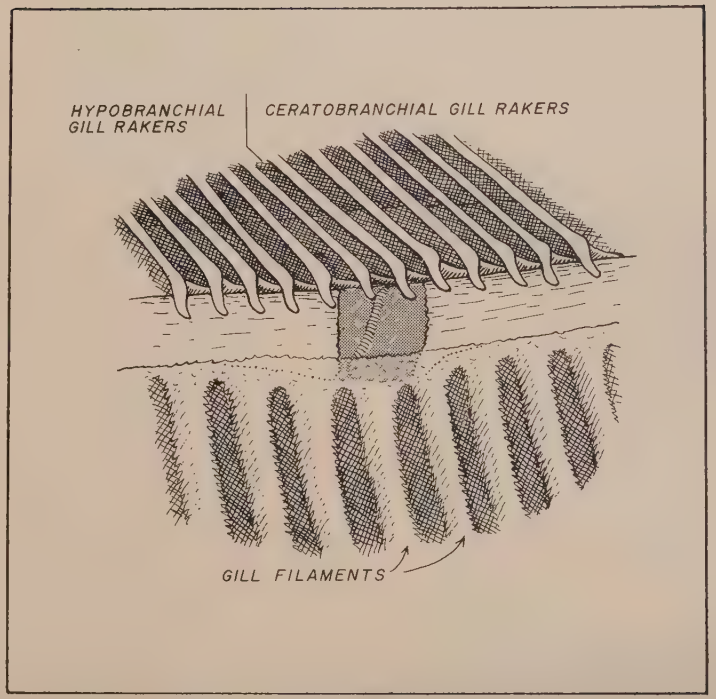


FIGURE 4. Enlargement of a portion of the lower limb of the first gill arch of a 135 mm S. L. specimen of *Opisthonema berlangai*, showing the junction of the hypobranchial and ceratobranchial segments.

FIGURA 4. Porción agrandada del miembro inferior del primer arco branquial de un espécimen de 135 mm de L. E. de *Opisthonema berlangai*, en la que se muestra la unión de los segmentos hipobranquial y ceratobranquial.

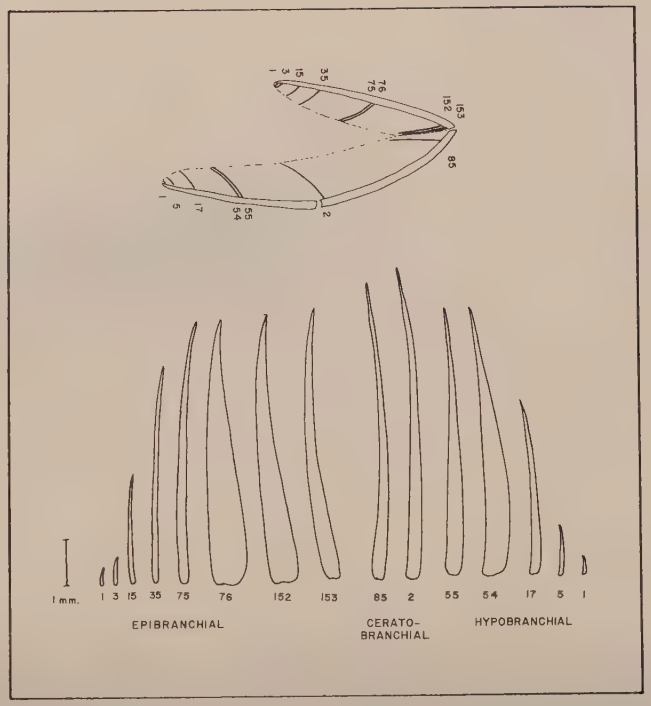
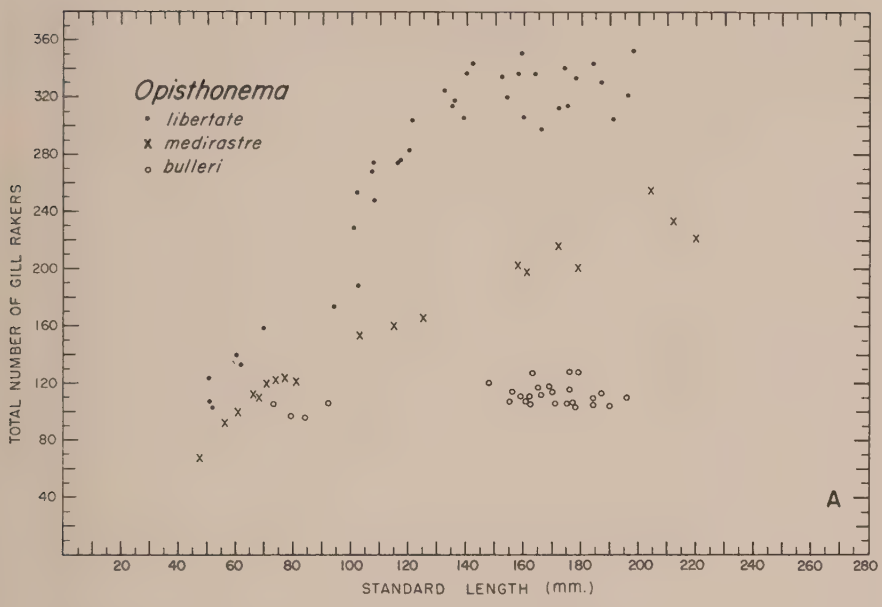


FIGURE 5. Frontal outlines of various gillrakers from the first gill arch of a 163 mm S. L. specimen of *Opisthonema libertate* with 153 epibranchial, 90 ceratobranchial, and 110 hypobranchial gillrakers. The rakers are drawn to scale; three rakers with lateral expansions are shown.

FIGURA 5. Contornos frontales de varias branquispinas del primer arco branquial de un espécimen de 163 mm de L. E. de *Opisthonema libertate* con 153 branquispinas epibranquiales, 90 ceratobranquiales, y 110 hipobranquiales. Las branquispinas fueron dibujadas a escala; se muestran tres branquispinas con expansiones laterales.



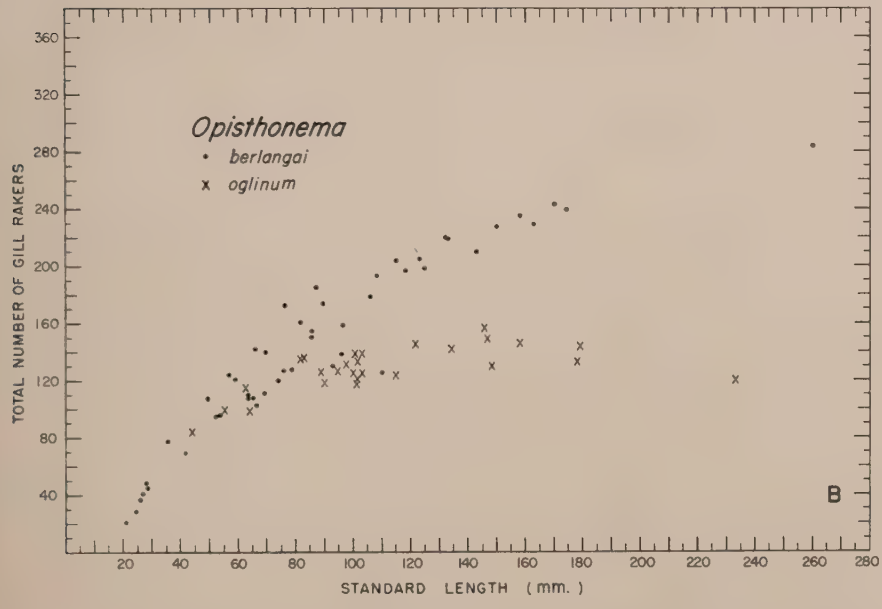


FIGURE 6. Relation of total number of gillrakers to standard length. A) *Opisthonema libertate, O. medirastre,* and *O. bulleri.* B) *Opisthonema berlangai* and *O. oglinum.*

FIGURA 6. Relación entre el número total de branquispinas y la longitud estándar. A) *Opishtonema libertate, O. medirastre y O. bulleri.* B) *Opisthonema berlangai y O. oglinum.*

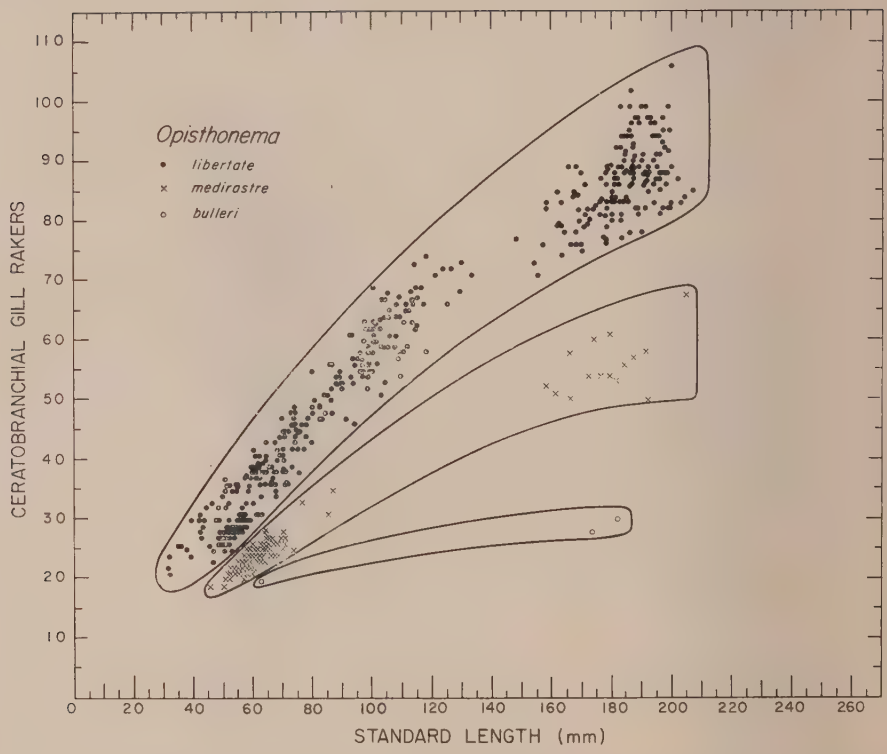


FIGURE 7. Relation of the number of ceratobranchial gillrakers to standard length for the three Pacific coastal species, *Opisthonema libertate, O. medirastre,* and *O. bulleri,* from Peru, Panama, and Costa Rica. Three specimens from El Salvador (including the holoytpe of *O. libertate*) and the only specimen examined from Colombia are included. In this figure and in similar subsequent figures, perimeters have been drawn around the values to represent the gillraker profiles.

FIGURA 7. Relación entre el número de branquispinas ceratobranquiales y la longitud estándar de las tres especies costaneras del Pacífico, *Opisthonema libertate, O. medirastre,* y *O. bulleri,* del Perú, Panamá y Costa Rica. Se incluyen tres especímenes de El Salvador (incluyendo el holotipo de *O. libertate*) y el único espécimen de Colombia que ha sido examinado. En esta figura y en las figuras similares subsiguientes, líneas perimétricas han sido dibujadas encerrando los valores para representar los perfiles de las branquispinas.

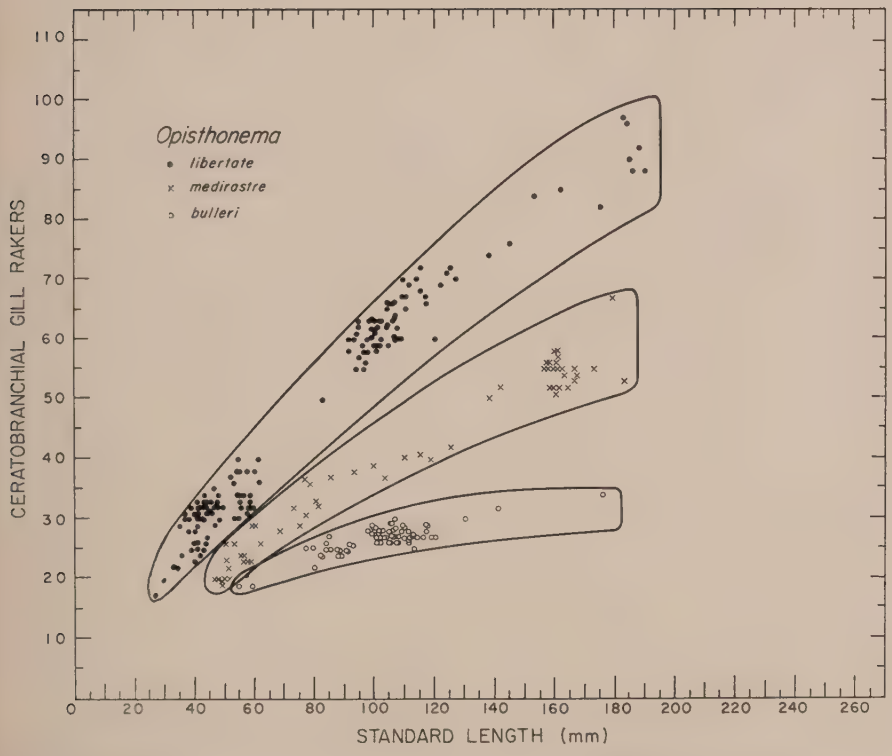


FIGURE 8. Relation of the number of ceratobranchial gillrakers to standard length for the three Pacific coastal species, *Opisthonema libertate*, *O. medirastre*, and *O. bulleri*, from southern Mexico (geographical limits defined in text).

FIGURA 8. Relación entre el número de branquispinas ceratobranquiales y la longitud estándar para las tres especies costaneras del Pacífico, *Opisthonema libertate*, *O. medirastre*, y *O. bulleri*, del sur de México (los límites geográficos se definen en el texto).

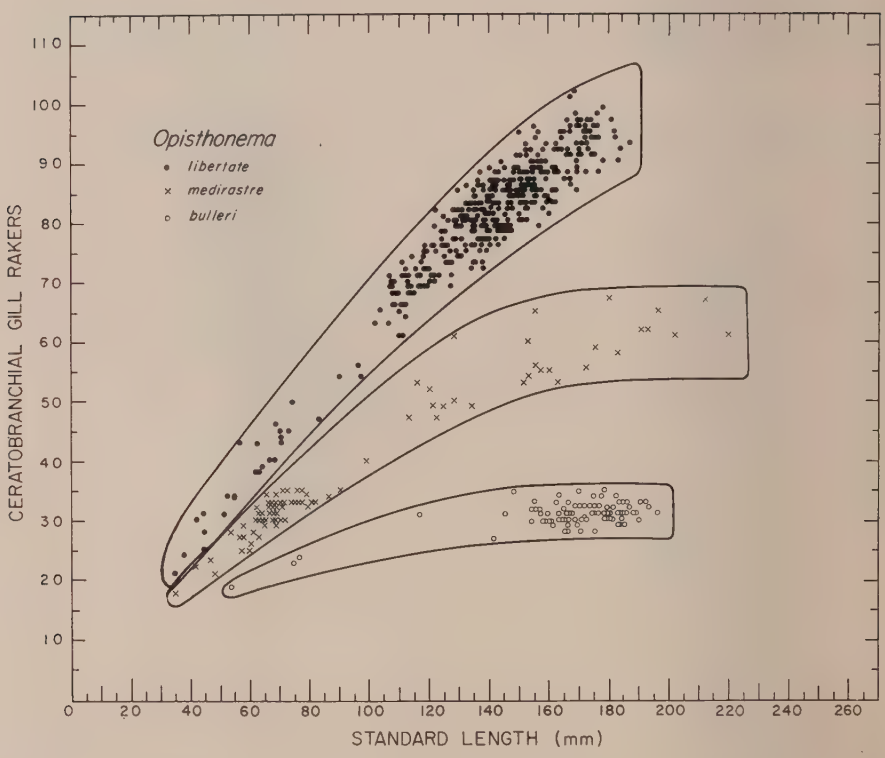


FIGURE 9. Relation of the number of ceratobranchial gillrakers to standard length for the three Pacific coastal species, *Opisthonema libertate, O. medirastre,* and *O. bulleri,* from northern Mexico (geographical limits defined in text). The only specimen examined from California (*O. medirastre*) is included).

FIGURA 9. Relación entre el número de branquispinas ceratobranquiales y la longitud estándar para las tres especies costaneras del Pacífico *Opisthonema libertate, O. medirastre,* y *O. bulleri,* del norte de México (los límites geográficos se definen en el texto). Se incluye el único espécimen de California que ha sido examinado *(O. medirastre).*

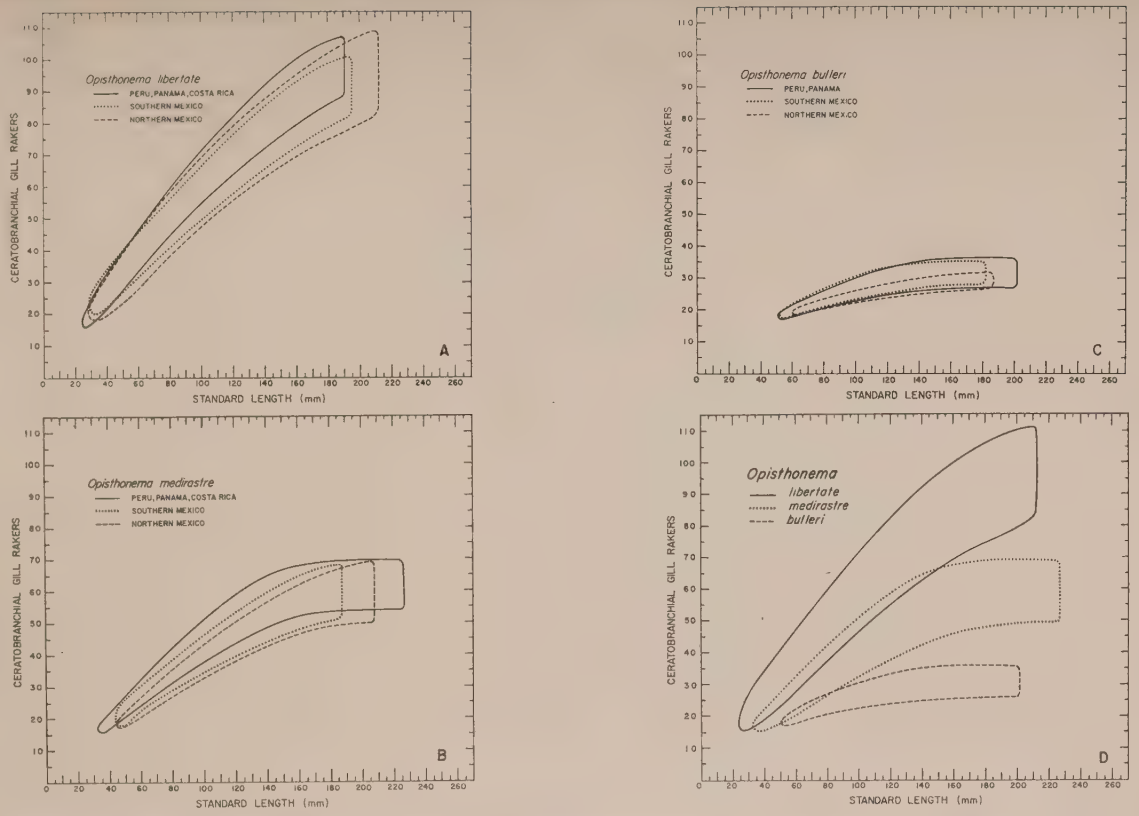


FIGURE 10. Ceratobranchial gillraker profiles from Figs. 7, 8, and 9. A) *Opisthonema libertate*. B) *O. medirastre*. C) *O. bulleri*. D) The three Pacific coastal species, with geographical areas combined.

FIGURA 10. Perfiles de branquispinas ceratobranquiales de las Figs. 7, 8, y 9. A) *Opisthonema libertate*. B) *O. medirastre*. C) *O. bulleri*. D) *Las tres especies* costaneras del Pacífico con áreas geográficas combinadas.

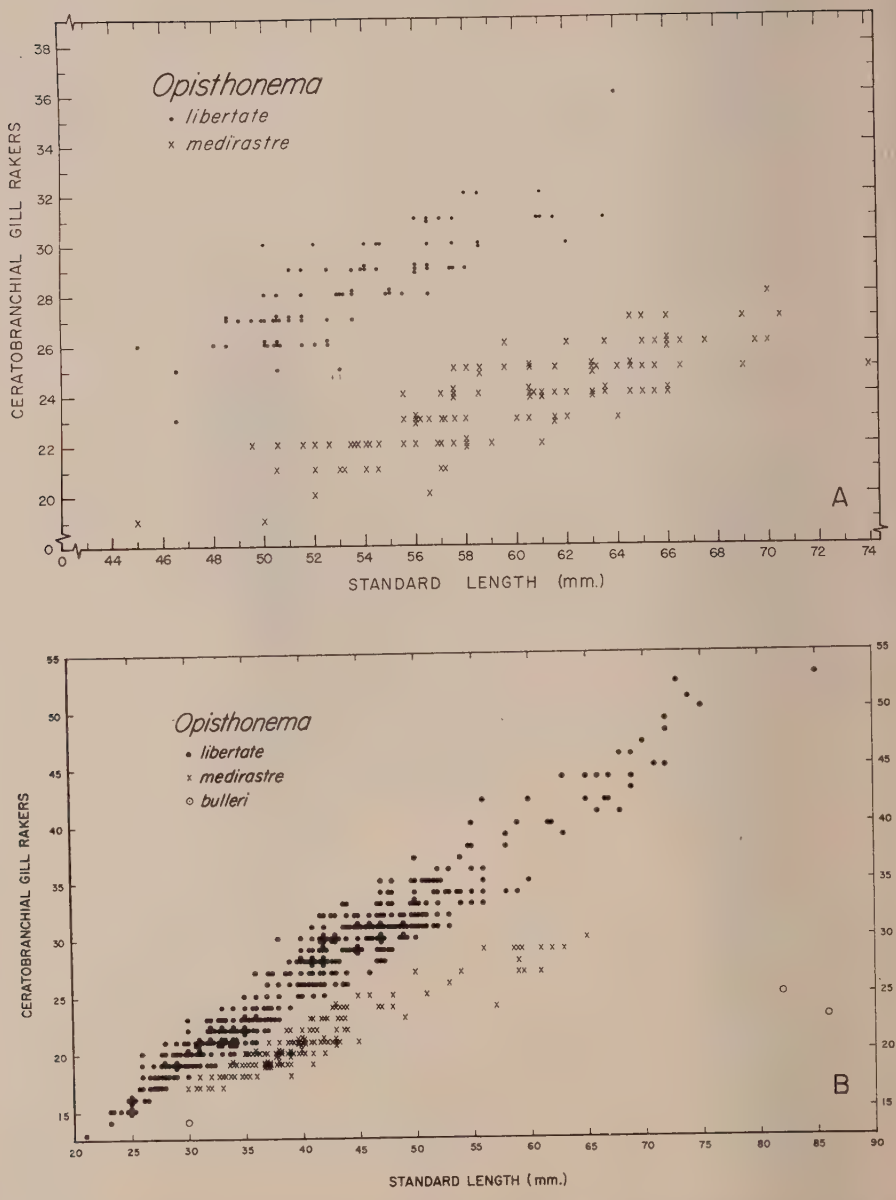


FIGURE 11. Relation of the number of ceratobranchial gillrakers to standard length for specimens from the same locality. A) *Opisthonema libertate* and *O. medirastre* of a single collection from Sonora, Mexico. B) *Opisthonema libertate, O. medirastre,* and *O. bulleri* of 19 collections from the Gulf of Nicoya, Costa Rica.

FIGURA 11. Relación entre el número de branquispinas ceratobranquiales y la longitud estándar para ejemplares pequeños de la misma localidad. A) *Opisthonema libertate* y *O. medirastre* de una sola recolección de Sonora, México. B) *Opisthonema libertate, O. medirastre* y *O. bulleri* de 19 recolecciones del Golfo de Nicoya, Costa Rica.

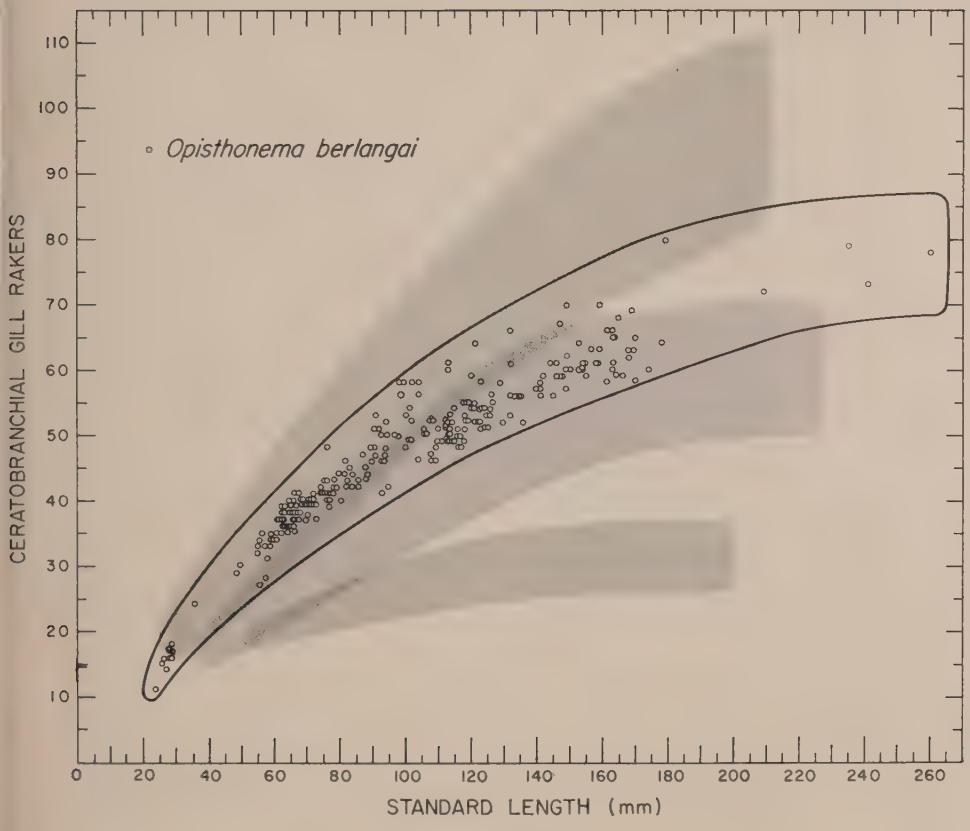


FIGURE 12. Relation of the number of ceratobranchial gillrakers to standard length for *Opisthonema berlangai*. The ceratobranchial gillraker profiles for the three Pacific coastal species, *Opisthonema libertate, O. medirastre,* and *O. bulleri,* are shown for comparison.

FIGURA 12. Relación entre el número de branquispinas ceratobranquiales y la longitud estándar para *Opisthonema berlangai*. Los perfiles de branquispinas ceratobranquiales para las tres especies costaneras del Pacífico, *Opisthonema libertate, O. medirastre,* y *O. bulleri,* se muestran con fines comparativos.

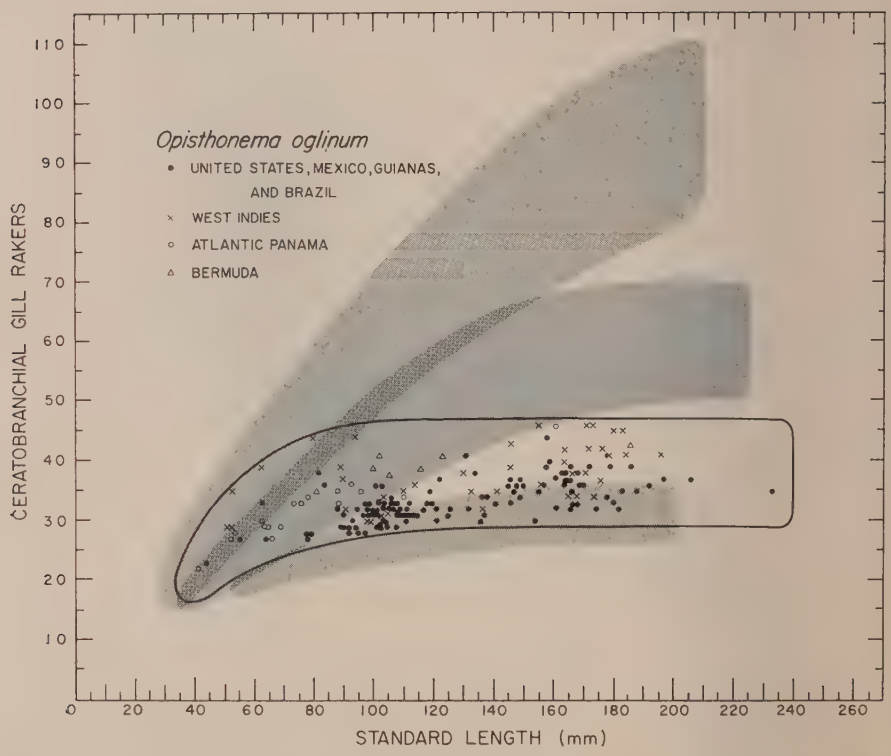


FIGURE 13. Relation of the number of ceratobranchial gillrakers to standard length for *Opisthonema oglinum* from four general geographical areas. The ceratobranchial gillraker profiles for the three Pacific coastal species, *Opisthonema libertate, O. medirastre,* and *O. bulleri,* are shown for comparison.

FIGURA 13. Relación entre el número de branquispinas ceratobranquiales y la longitud estándar para *Opisthonema oglinum* de cuatro áreas geográficas generales. Los perfiles de las branquispinas ceratobranquiales de las tres especies costaneras del Pacífico, *Opisthonema libertate, O. medirastre,* y *O. bulleri,* se muestran con fines comparativos.

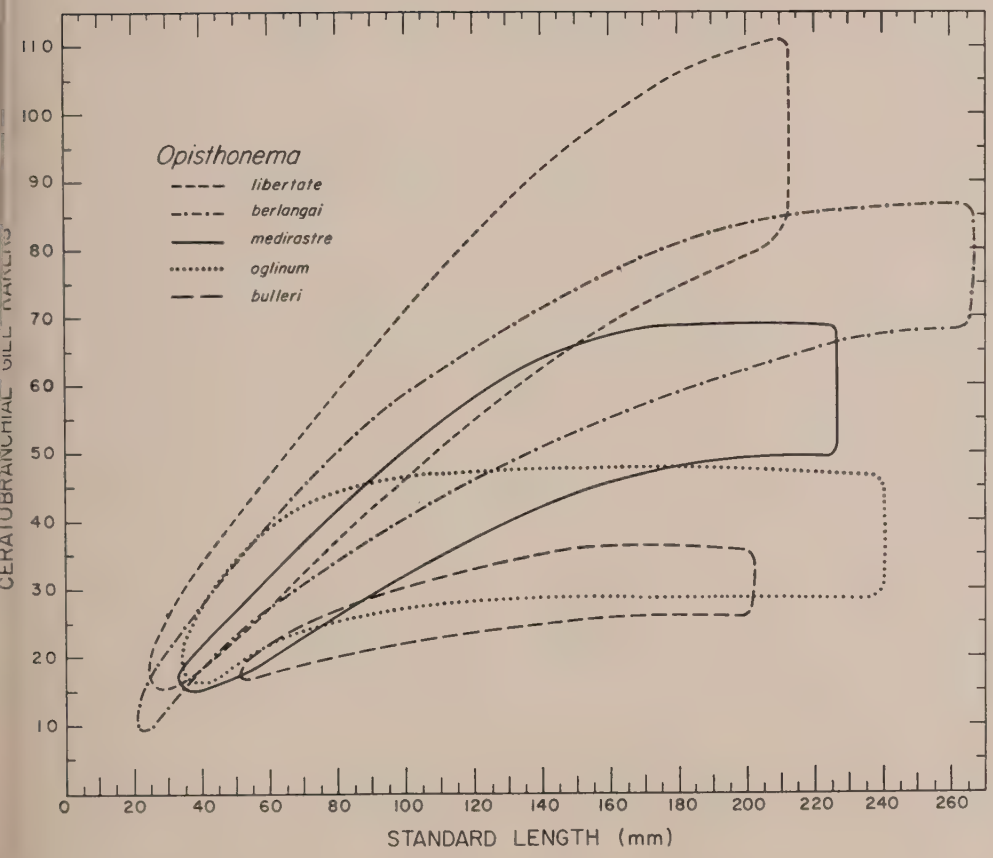


FIGURE 14. Ceratobranchial gillraker profiles for the five species of *Opisthonema*.

FIGURA 14. Perfiles de las branquispinas ceratobranquiales para las cinco especies de *Opisthonema*.

TABLE 1. Fin rays, scale rows, scutes, and vertebrae in the five species of *Opisthonema*—ranges of counts with the mean value in parentheses below each range.

TABLA 1. Radios de las aletas, hileras de escamas, escudetes y vértebras de las cinco especies de *Opisthonema*—figuran los límites de las cuentas, apareciendo el valor medio en paréntesis debajo de cada límite.

Species	Dorsal rays	Anal rays	Pectoral rays	Pelvic rays	Scale rows	Prepelvic scutes	Postpelvic scutes	Vertebrae
Especies	**Radios dorsales**	**Radios anales**	**Radios pectorales**	**Radios pélvicos**	**Hileras de escamas**	**Escudetes prepélvicos**	**Escudetes postpélvicos**	**Vértebras**
libertate	17-20	19-22	17-18	8-9	43-50	17-19	14-16	44-48
	(18.6)	(20.8)	(17.4)	(8.95)	(46.3)	(17.9)	(15.2)	(46.0)
berlangai	19-20	19-22	17-19	8-9	47-50	17-18	15-17	45-47
	(19.4)	(20.7)	(17.4)	(8.90)	(48.7)	(17.9)	(16.1)	(46.0)
medirastre	17-20	19-23	16-19	8-9	45-52	18-19	15-17	46-48
	(19.2)	(21.0)	(17.9)	(8.88)	(49.3)	(18.2)	(16.2)	(47.1)
bulleri	18-21	20-23	17-19	8-9	48-53	17-19	16	46-48
	(19.6)	(21.4)	(17.8)	(8.90)	(50.8)	(18.0)	(16.0)	(47.0)
oglinum	18-22	22-25	16-19	8-9	42-49	18-19	15-16	45-49
	(20.0)	(23.5)	(17.4)	(8.60)	(45.5)	(18.2)	(15.6)	(46.3)

TABLE 2. Body proportions of larger specimens of the five species of *Opisthonema*, in ranges of percent of standard length.

TABLA 2. Proporciones corporales de los especímenes grandes de las cinco especies de *Opisthonema;* los límites representan el porcentaje de la longitud estándar.

Species	Body depth	Head length	Dorsal fin lobe length	Last dorsal ray length	Pectoral fin length	Pelvic fin length
Especies	Profundidad corporal	Longitud de la cabeza	Longitud del lóbulo de la aleta dorsal	Longitud del último radio dorsal	Longitud de la aleta pectoral	Longitud de la aleta pélvica
libertate	27.8-37.5	21.5-27.2	14.0-19.7	34.7-46.5	17.2-21.8	8.6-11.5
berlangai	29.2-33.3	21.6-25.5	15.9-20.3	34.5-40.2	17.2-20.2	9.2-12.0
medirastre	27.1-37.0	20.8-24.6	14.4-18.2	32.8-42.7	16.7-20.7	8.5-10.5
bulleri	25.0-33.3	21.4-24.4	12.8-16.2	31.6-39.3	15.8-19.7	7.9-10.8
oglinum	30.7-39.6	19.0-24.4	15.1-20.8	33.3-40.3	17.2-20.7	8.6-11.5

TABLE 3. Numbers of ceratobranchial gillrakers and size ranges in millimeters of standard length at which they occur in the five species of *Opisthonema*. This table serves as a key to species identification.

TABLA 3. Número de branquispinas ceratobranquiales y límites de tamaños en milímetros de la longitud estándar a los que aparecen en las cinco especies de *Opisthonema*. Esta tabla sirve de clave para la identificación de las especies.

Ceratobranchial Gillrakers Branquispinas Ceratobranquiales	SIZE RANGE (in mm S. L.) — LIMITES DE TAMAÑOS (en mm de L. E.)											Ceratobranchial Gillrakers Branquispinas Ceratobranquiales
	PACIFIC COASTAL SPECIES — ESPECIES COSTANERAS DEL PACIFICO									GALAPAGOS GALAPAGOS	ATLANTIC ATLANTICO	
	Peru, Panama, Costa Rica Perú, Panamá, Costa Rica			Southern Mexico Sur de México			Northern Mexico Norte de México					
	bulleri	*medirastre*	*libertate*	*bulleri*	*medirastre*	*libertate*	*bulleri*	*medirastre*	*libertate*	*berlangai*	*oglinum*	
14										21-31		14
15										22-33		15
16										23-35		16
17			23-31							24-37		17
18		32-44	24-33					40-52		25-39		18
19	49-68	33-46	24-35	49-68	39-53			42-55		26-40		19
20	51-74	35-48	25-37	52-74	40-55		58-74	44-59	25-42	27-42		20
21	55-82	36-51	26-39	55-81	41-57	25-37	61-84	46-62	26-45	29-45	34-58	21
22	58-93	38-54	27-41	58-90	42-60	26-40	66-95	47-65	27-48	30-47	34-62	22
23	63-103	40-57	28-43	62-99	44-63	26-42	72-107	50-69	28-50	32-49	35-67	23
24	67-114	43-60	29-45	66-113	45-65	27-44	78-125	52-72	29-52	33-52	36-74	24
25	72-120	45-63	30-46	70-125	47-68	28-46	85-144	54-75	30-55	35-54	37-81	25
26	76-150	47-66	31-48	74-125	48-72	29-48	94+	57-79	31-57	36-57	38-88	26
27	81+	49-69	33-50	78-150	50-75	30-50	101+	59-83	33-59	38-60	39-99	27
28	86+	51-72	34-52	83+	52-78	31-52	110+	61-86	34-60	39-62	40-114	28
29	91+	53-74	35-53	88+	54-81	32-55	118+	63-89	35-62	41-65	41+	29
30	96+	55-78	36-56	93+	57-85	33-57	131+	65-92	36-65	42-67	43+	30
31	102+	56-81	37-57	99+	59-88	35-59	145+	67-95	38-67	44-70	44+	31
32	108+	58-84	38-58	104+	62-91	36-61	165+	70-99	39-69	45-73	45+	32
33	114+	60-87	40-60	113+	64-95	38-63		72-103	40-71	47-76	46+	33
34	121+	63-91	41-62	123+	67-99	39-66		75-106	42-73	48-79	48+	34
35	132+	65-93	42-64	138+	69-103	41-68		77-111	43-75	50-82	50+	35
36	143+	67-96	44-65		72-108	43-70		79-115	44-77	51-85	52+	36
37		68-99	45-67		74-112	44-73		82-118	46-79	53-88	54+	37
38		70-103	47-69		77-116	46-75		84-122	47-81	55-91	56+	38
39		73-106	48-70		79-120	47-77		87-126	49-83	57-95	58+	39
40		75-109	50-72		82-124	49-79		89-130	50-85	58-98	61+	40
41		77-112	51-74		85-129	51-81		92-134	52-87	60-102	64+	41
42		79-116	53-76		87-133	53-84		95-139	53-90	62-105	67+	42
43		81-120	54-78		90-138	55-86		97-144	54-92	63-108	70+	43
44		83-123	56-80		92-142	56-88		100-149	56-94	65-112	75+	44
45		85-127	57-82		95-147	58-91		103-154	57-97	67-116	79+	45
46		87-131	59-84		98-153	60-93		106-160	59-99	69-120	87+	46
47		90-136	61-85		100-159	61-95		109-167	60-101	71-124	95+	47
48		92-140	62-87		103-165	63-97		112-177	61-103	73-129		48
49		95-144	64-89		106-172	65-100		115-197	63-105	75-133		49
50		97-149	65-91		109-180	67-102		118+	65-107	77-137		50
51		99-157	67-93		112+	69-105		121+	67-109	79-142		51
52		102-166	68-95		115+	71-107		124+	68-111	81-146		52
53		104+	70-97		118+	73-109		127+	70-114	83-151		53
54		107+	72-99		122+	75-112		130+	71-116	86-156	—	54
55		109+	73-101		125+	77-114		134+	73-119	88-161		55

56	112 +	75-103	129 +	78-117	137 +	75-122	91-166		56
57	114 +	77-105	132 +	80-120	140 +	77-124	93-171		57
58	116 +	78-107	136 + +	82-122	144 +	78-127	95-176		58
59	122 +	80-110	139 +	84-125	148 +	80-130	98-181		59
60	124 +	81-112	143 +	86-128	151 +	82-133	100-187		60
61	125 + +	83-114	147 + +	88-130	156 +	84-136	103-192		61
62	127 +	85-117	150 + +	90-133	160 +	85-139	106-198		62
63	131 +	87-119	154 +	92-136	164 + +	86-142	110-205		63
64	135 + +	88-121	157 + +	94-139	169 + +	89-145	113-210		64
65	139 + +	90-124	162 + +	96-142	173 +	91-148	116-217		65
66	144 + +	91-126	166 + +	98-144	178 +	92-151	119-225		66
67	149 +	93-128	171 + +	100-147	183 +	94-154	122-236		67
68	159 + +	95-131	177 + +	102-150	190 +	96-158	126 +		68
69	168 +	97-133		104-153	198 +	98-161	129 +		69
70		99-136		106-156		100-164	132 +		70
71		101-139		108-158		102-168	136 +		71
72		102-141		110-161		104-171	139 +		72
73		104-144		112-164		106-175	142 +		73
74		105-147		114-167		109-180	145 +		74
75		107-149		117-170		110-184	150 +		75
76		109-152		119-173		112-188	154 + +		76
77		111-155		121-177		114-192	158 +		77
78		113-158		123-180		117-196	162 +		78
79		114-161		125-184		119-200	166 + +		79
80		116-164		127-188		121-205	171 + +		80
81		118-167		130-192		123 +	176 +		81
82		120-170		132 + +		125 +	181 +		82
83		121-173		134 +		128 + +	190 + +		83
84		123-176		136 +		130 +	197 + +		84
85		125-180		139 + +		132 +	206 +		85
86		127-183		141 + +		135 +	220 +		86
87		129-187		143 +		137 + +			87
88		131-190		146 +		140 +			88
89		133 +		148 +		143 +			89
90		135 +		151 + +		145 +			90
91		137 +		153 +		148 + +			91
92		139 +		156 + +		150 +			92
93		141 + +		159 + +		153 +			93
94		143 +		162 + +		156 +			94
95		146 +		165 + +		158 +			95
96		148 +		169 + +		161 +			96
97		151 + +		172 +		164 + +			97
98		153 +		176 + +		167 +			98
99		156 +		180 + +		170 + +			99
100		159 +		185 + +		173 + +			100
101		162 + +				176 +			101
102		165 + +				180 + +			102
103		166 +				183 + +			103
104		172 +				186 + +			104
105		177 + +				190 + +			105
106		182 +				194 + +			106
107						198 + +			107
108						202 + +			108
109						206 + +			109

ANALISIS DE LAS BRANQUISPINAS Y DENOMINACION DE LAS ESPECIES DEL ARENQUE DE HEBRA GENERO *OPISTHONEMA*

por

Frederick H. Berry[1] e Izadore Barrett

RESUMEN

Los arenques de hebra, género *Opisthonema,* familia Clupeidae, son peces marinos que se encuentran sólo en aguas tropicales y subtropicales cerca a ambas costas del continente americano. El género está compuesto de una especie en el Atlántico y de cuatro en el Pacífico. *Opisthonema oglinum* (LeSueur), única especie que medra el Océano Atlántico occidental, se encuentra del Brasil a Massachusetts, en Bermuda, y las Indias Occidentales. *Opisthonema libertate* (Günther), *Opisthonema bulleri* (Regan), y *Opisthonema medirastre,* especie nueva, son especies costaneras del Pacífico que aparecen entremezcladas del Perú a México (ocasionalmente por lo menos una de ellas en California). *Opisthonema berlangai,* especie nueva, está confinada a la vecindad de las Islas Galápagos.

Sólo pequeñas diferencias morfológicas existen entre las cinco especies. La diferenciación práctica de las especies se basa en la combinación de dos consideraciones: (1) el área geográfica de aparición y (2) la forma en que el número de branquispinas aumenta en relación con la longitud estándar.*

El número de branquispinas en los tres segmentos del primer arco branquial aumenta, con el crecimiento del pez, hasta aproximadamente 120 mm L. E. en *O. oglinum,* hasta mayor tamaño en *O. bulleri, O. medirastre,* y *O. berlangai,* y aparentemente durante toda la vida en *O. libertate.* La cuenta y comparación del número de branquispinas en el segmento ceratobranquial del primer arco branquial es el método más conveniente para diferenciar las cinco especies. Los especímenes de aguas frías tienden a tener menor número de branquispinas que aquellos de aguas templadas.

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1.—U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries, Biological Laboratory, La Jolla, California.

* longitud estándar se abreviará a través de este escrito así: L. E.

nographic Collection (BOC); John E. Fitch y John Radovich, California Department of Fish and Game; W. I. Follett y Lillian Dempster, California Academy of Sciences (CAS); John P. Harville, San José State College; Carl L. Hubbs y Richard H. Rosenblatt, Scripps Institution of Oceanography (SIO); Giles W. Mead, Harvard University Museum of Comparative Zoology (MCZ); George S. Myers y Hugh DeWitt, Stanford University Natural History Museum (SU); Leonard P. Schultz, U. S. National Museum (USNM); y Boyd W. Walker y Wayne J. Baldwin, University of California en Los Angeles (UCLA). Obligados estamos con Clifford L. Peterson (IATTC) por el suministro de los datos sobre los cuales se basa la Fig. 11B. Estamos especialmente agradecidos a G. Palmer, British Museum (Natural History), por la información sobre los especímenes tipo de *Opisthonema libertate* y *O. bulleri*. Sugerencias o comentarios técnicos de gran valor en el análisis y comprensión de los datos contenidos en el presente manuscrito y su preparación para publicación fueron hechos por Elbert H. Ahlstrom, Franklin G. Alverson, W. I. Follet, Jack W. Gehringer, Carl L. Hubbs, David Kramer, John S. MacGregor, Romeo Mansueti, Charles P. O'Connell, Clifford L. Peterson, Richard H. Rosenblatt, Milner B. Schaefer y Stewart Springer. También hacemos extensivos nuestros agradecimientos al Sr. Enrique L. Díaz por la traducción de este texto al español.

INTRODUCCION

Los arenques de hebra son peces marinos del género clupeido *Opisthonema* que se encuentra sólo en los océanos Atlántico occidental y Pacífico Oriental, principalmente en las aguas tropicales y subtropicales. Se caracterizan por una prolongación filamentosa del último radio de la aleta dorsal, una hilera de escudetes a lo largo de la línea media ventral, hileras de escamas que cruzan el dorso entre la cabeza y la aleta dorsal, y una molleja elíptica de paredes delgadas. Las dos últimas características diferencian a los arenques de hebra de las alosas de molleja (nombre inglés, "gizzard shad"; género *Dorsoma*), que habitan las aguas continentales de Norte y Centroamérica y entran ocasionalmente en aguas costeras marinas en los esteros.

En el Pacífico, antes del cambio abrupto en la técnica de carnada viva a la de barcos rederos para la pesca del atún (Schaefer, 1961), los arenques de hebra eran de importancia secundaria como peces de carnada viva (Schaefer, 1954). Han sido capturados con este fin en la Bahía de San Diego, California, al sur hasta el Perú, y en las Islas Galápagos, donde en determinado tiempo y áreas los arenques de hebra formaron parte substancial de la captura de peces de carnada viva (Alverson y Shimada, 1957). En el Atlántico, los arenques de hebra se consideran como una fuente potencial suplementaria de pescado para usos industriales. La pesca experimental de los arenques de hebra en el Golfo de México y la perspectiva para su desarrollo pesquero comercial ya han sido tratados por Butler (1961). Con anterioridad al presente estudio sólo dos especies han sido

reconocidas: *Opisthonema oglinum* (LeSueur, 1818) en el Atlántico y *Opisthonema libertate* (Günther, 1866) en el Pacífico. Hemos determinado que una sola especie sí se presenta en el Atlántico, pero también cuatro especies existen en el Pacífico.

Aún cuando se ha investigado un cierto número de caracteres morfológicos, la diferenciación de estas especies se basa esencialmente en diferencias con respecto al número de branquispinas. Por la importancia de las branquispinas en la taxonomía de este género y la posibilidad de que sean de igual importancia para otros grupos, hemos analizado la variación ontogénica y geográfica presente en esta estructura y presentamos un método práctico para evaluar las diferencias existentes entre estas especies con base en la mencionada característica.

TAXONOMIA

Opisthonema Gill, 1861

Opisthonema Gill, 1861:37 (Especie tipo, *Opisthonema thrissa* Gill, 1861 (*non* Linnaeus; = *Megalops oglina* LeSueur, 1818), por designación original).

Filialosa Fowler, 1944:207 (Especie tipo, *Meletta libertatis* Günther, 1866, por designación original).

Caracteres.—Cuerpo lateralmente comprimido, que se angosta ventralmente hasta terminar en una hilera de escudetes; perfil ventral del cuerpo más encorvado que el dorsal; profundidad máxima generalmente entre el origen de las aletas dorsal y pélvica.

Parte superior de la cabeza ligeramente rugosa. Arborizaciones dendríticas del sistema de la línea lateral en los huesos opercular y suborbitario (también en las escamas inmediatamente posteriores al occipital y en el borde superior de la clavícula). Hocico moderadamente puntiagudo; mandíbula inferior levemente proyectada (mandíbulas aproximadamente iguales). Ninguna escotadura aparente en la sínfisis premaxilar. Párpado adiposo presente, denso y anteriormente apical. Premaxilares cortos, maxilares ocupando la mayor distancia transversal de la abertura bucal; no existe ningún hueso suplementario entre la terminación del premaxilar y el maxilar; dos supramaxilares, el anterior más pequeño; margen posterior de la mandíbula superior formado por las terminaciones del maxilar y la parte posterior dorsal del supramaxilar, redondeado, extendiéndose más abajo de la parte anterior de la pupila, la mayor profundidad de su margen generalmente mayor que el diámetro de la pupila. Mandíbula sin dientes en los estados juveniles y adultos (en ejemplares de 30 mm de L. E. existen dientes sinfíseos en los dentarios y dientes marginales en los maxilares); contados caninos, encorvados y delgados en el suelo de la boca inmediatamente anteriores a la abertura esofágica, pero ausentes en el paladar.

Opérculo y preopérculo relativamente alargados dorsoventralmente y angostos anteriormente. No existen notorias estriaciones óseas en el opérculo. Seis radios branquióstegos, el último obtuso, expandido distal-

mente y formando, con el margen ventral del subopérculo, un ángulo de 90° aproximadamente.

Un pliegue dérmico bilobulado y débil en el margen vertical anterior de la clavícula, y otro pliegue mayor dirigido anteriormente en el lado dorsal del margen anterior de la clavícula, con un surco entre el pliegue y el istmo. Membranas branquiales unidas y superpuestas al istmo anteriormente, la membrana de la izquierda superpuesta a la del lado derecho. Pseudobranquias relativamente grandes.

Branquispinas relativamente largas y delgadas, cuyo número en el primer arco aumenta con el crecimiento (hasta cerca de 120 mm de L. E. en una especie, y hasta mayor tamaño o durante el transcurso vital en otras) por adición en los bordes anteriores de las ramas superiores e inferiores; el mayor número de branquispinas se encuentra en el primer arco (hasta 353), decreciendo progresivamente en el segundo, tercero, y cuarto arcos; el tercer y cuarto arcos poseen hileras de branquispinas en ambos lados, el medial y el lateral; las branquispinas de la rama inferior cerca al ángulo con la rama superior, no se superponen con la de ésta última, sino que se disponen lateralmente a ellas en los especímenes más grandes de las especies que poseen un elevado número de branquispinas; la mayoría de las branquispinas tienen forma lanceolada normal, pero algunas, especialmente en la rama superior de los especímenes grandes, se expanden lateralmente.

Línea media ventral del cuerpo formada por escudetes endurecidos con espinas dirigidas posteriormente, que se extiende de la garganta a la abertura anal (17 a 19 prepélvicas, 14 a 17 postpélvicas; 32 a 35 en total).

Escamas cicloideas con pequeños festones semicirculares en el margen posterior, que cubren el cuerpo y se extienden sobre la aleta caudal, estando ausentes en la cabeza; una hilera de escamas de baja elevación a lo largo de la inserción de las aletas dorsal y anal; una escama axilar alargada extendida hasta cerca de las 2/3 partes de la longitud de la aleta pélvica a lo largo de su margen dorsal; escama axilar de la aleta pectoral ausente; escamas deciduas que cubren las bases de las aletas pectoral y pélvica; hileras de escamas que se extienden de los escudetes ventrales, hacia arriba y a través de la convexidad dorsal al frente de la aleta dorsal, y a través del dorso posteriormente a la aleta dorsal; cerca de 42 a 53 hileras transversas de escamas del occipital a la base de la aleta caudal.

La aleta dorsal está insertada aproximadamente a la distancia media entre la punta del hocico y la base de la aleta caudal (su origen más cercano a la parte terminal del hocico); todos los radios son segmentados; los primeros 5 radios no ramificados, el resto ramificados, el último radio ramificado hasta su base pero sus ramas están secundariamente fusionadas en los ejemplares grandes (17-22 radios dorsales). La aleta dorsal posee un lóbulo anterior integrado por el 5to, 6to y 7mo radios (el lóbulo cerca del 13-21% de la L. E.); los radios dorsales crecen en longitud desde el minúsculo primer radio (del cual carecen algunos especímenes) hasta

el 6to radio y decrecen en longitud desde el 6to radio hasta el penúltimo radio; el penúltimo radio cerca del doble de la longitud del radio que le precede, el último radio es grueso en su base, a manera de un filamento cónico, alargado, cuyo diámetro decrece progresivamente hasta terminar en punta, extendiéndose hasta cerca de la base de la aleta caudal (longitud del filamento cerca del 31-47% de la L. E.).

Aleta anal larga, baja, e insertada muy posteriormente en el cuerpo; el primer radio generalmente no segmentado (y ocasionalmente el 2do), el resto segmentado (19-25 radios anales); el primer radio frecuentemente minúsculo el segundo corto, del 3ro al 5to generalmente aumentado en longitud y del 6to al 10mo decreciendo longitudinalmente; el resto de los radios iguales o incrementando longitudinalmente hasta cerca de los últimos 3 radios; en estos 3 últimos radios la longitud aumenta y el último radio es el más largo en esta aleta; el penúltimo radio es ligeramente más grueso que los que le preceden; el último radio es aproximadamente dos veces más grueso que el penúltimo radio y se ramifica en su base. Aparentemente existe una correlación positiva entre el número de radios de las aletas dorsal y anal—especímenes con un mayor número de radios dorsales vienen a tener un mayor número de radios anales—habiendo generalmente dos o más radios anales que radios dorsales.

Aleta caudal profundamente horquillada con lóbulos puntiagudos aproximadamente iguales (10 + 9 radios principales).

Aletas pectorales puntiagudas, el 3ro y 4to radios son los más largos (cerca de 15-22% de la L. E.); están insertas inferiormente en el flanco, debajo del margen posterior del opérculo; todos los radios son segmentados; el primer radio no ramificado, el resto ramificados; el primer radio es aplanado y muy junto al 2do radio (16-19 radios pectorales); una convexidad carnosa y una zona dentada ventral que tiene por objeto la recepción de la parte dorsal de la aleta contra el cuerpo.

Aletas pélvicas puntiagudas, el 2do y 3ro radios son los más largos (7 a 12% de la L. E.); insertas un poco arriba de los escudetes ventrales, en un lugar debajo del punto de la inserción de la aleta dorsal; todos los radios son segmentados; el primer radio es aplanado y muy junto al segundo radio; el primer radio no ramificado, el resto ramificado; generalmente 9 radios, raramente 8 radios en uno o ambos lados.

Vértebras 44-49.

Canal alimentario con esófago que se abre en 2 hendiduras faríngeas protuberantes, anterodorsales y bilaterales; el estómago se extiende posteriormente (hasta cerca del 20% de la L. E.), se encorva anteriormente y termina en una molleja de forma elíptica y de paredes relativamente delgadas; el intestino se extiende posteriormente (hasta cerca del 30% de la L. E.), se encorva anteriormente hasta cerca de la terminación de la molleja, para luego encorvarse de nuevo y extenderse en línea recta hasta la abertura anal. Un pequeño grupo de cecas pilóricas al frente del intestino que se agrandan formando una masa de apéndices cecales a la dere-

cha de los pliegues intestinales. Un conducto neumático que une la vejiga de aire con la parte posterodorsal del estómago.

Pigmentación intraespecíficamente variable en especímenes preservados. Los siguientes caracteres ocurren en todas las especies, pero la presencia de los cuatro últimos en un solo espécimen es rara: 1) La superficie dorsal es negruzca de un tercio a un medio hacia abajo, para luego continuar cambiando poco a poco hasta que toma un color plateado en la parte lateral inferior y en el margen ventral. 2) Aleta dorsal con margen negruzco y el filamento, cambiando paulatinamente de color hasta obtener una porción basal obscura o clara; aleta caudal obscura con una raya negruzca en cada lóbulo extendida desde su base hasta su terminación; aletas pectorales con un margen dorsal obscuro; aletas anal y pélvica claras. 3) Una mancha opercular relativamente grande, redondeada, generalmente alargada verticalmente y usualmente de mayor diámetro que la pupila. 4) De una a varias filas irregulares compuestas de un número variable de manchas más pequeñas situadas en la parte dorsolateral de la superficie del cuerpo, que empiezan inmediatamente posterior a la mancha opercular y que comúnmente se extienden debajo o atrás de la inserción de la aleta dorsal. 5) Un par de manchas dorsales, una a cada lado inmediatamente posterior al origen de la aleta dorsal. 6) Dos a seis rayas situadas en la parte dorsolateral de la superficie del cuerpo, que se extienden hasta el pedúnculo aproximadamente.

Sinonimia de los géneros.—El género *Filialosa,* propuesto por Fowler en 1944, ha sido ignorado por autores subsecuentes y es un sinónimo de *Opisthonema.* Ninguno de los caracteres propuestos por Fowler para distinguir el género *Filialosa,* del Pacífico Oriental, del género *Opisthonema,* que fué restringido por él al Atlántico occidental, tiene categoría genérica; más bien, los caracteres reflejan diferencias interespecíficas y variación intraespecífica. Fowler asevera que la forma del Pacífico tiene un perfil ventral menos arqueado, cabeza de longitud ligeramente mayor, ojo más pequeño, maxilar menos inclinado, la abertura branquial extendida más hacia adelante, el origen de la aleta dorsal más hacia atrás, menor número de radios dorsales y anales, el último radio dorsal más largo, y las aletas pectorales más largas que la forma del Atlántico; además bandas de manchas negruzcas a los lados del cuerpo.

En la creación del género *Opisthonema,* Gill (1861:37) dió la siguiente sinonimia:

1) *Clupanodon* Lacépède, parcialmente [como sinónimo de *Opisthonema*].
2) *Opisthonema thrissa* Gill [como tipo de *Opisthonema*].
3) *Clupanodon thrissa* Lacépède [como sinónimo de *Opisthonema thrissa*].

Debido a que la intención aparente de Gill, fué la de restringir el género *Opisthonema* al Atlántico occidental, oponiéndose a los informes de Lacépède y autores previos en la cual combinan las formas de la China y del Atlántico, la especie tipo debe subsistir como *Opisthonema thrissa* Gill

(*non* Linnaeus, 1758 = *Megalops oglina* LeSueur, 1818). Esta es esencialmente la forma como Jordan (1919:303) inscribió la especie tipo.

Opisthonema medirastre especie nueva (Fig. 1A)

Clupea (*Opisthonema*) *Bulleri* (*non* Regan), 1904:255 (parcialmente; el espécimen más grande, de 110 mm L. E., el cual fué recolectado con el lectotipo de *O. bulleri*).

Opisthonema libertate (*non* Günther), Radovich, 1961:27 (designado como "Pacific thread herring"; parcialmente, sólo el espécimen del Puerto de Los Angeles, California, 21 Dic. 1958).

Diagnosis.—Branquispinas ceratobranquiales aumentando en número con el correspondiente incremento de la longitud corporal hasta cerca de 170 a 200 mm de L. E.; en especímenes de 200 mm de L. E. se encuentran de 50 a 69 branquispinas ceratobranquiales (el incremento numérico de las branquispinas ceratobranquiales con respecto a la L. E. aparece en la Tabla 3 y en las Figs. 7, 8, y 9; la variación geográfica se encuentra en la Fig. 10B). Su distribución geográfica comprende las aguas costaneras del Pacífico Oriental del Perú a Los Angeles, California (Fig. 2A).

Descripción del holotipo [medidas en mm (% de la L. E. en paréntesis)].—Longitud estándar 175. Longitud a la horquilla 187 (106.9). Longitud total 219 (125.1). Longitud de la cabeza a la clavícula 41.1 (23.5), al margen distal del opérculo 43.8 (25.0). Longitud de la mandíbula superior 17.4 (9.9). Profundidad del maxilar 6.6 (3.8). Anchura del interorbitario 10.4 (5.9). Diámetro del ojo 11.8 (6.7). Longitud del hocico 12.0 (6.9). Longitud postorbitaria de la cabeza, tomada en sentido horizontal 18.1 (10.3), longitud máxima 23.7 (13.5). Profundidad corporal, tomada verticalmente del origen de la aleta dorsal 55.5 (31.7); del origen de la aleta dorsal al origen de la aleta pélvica 56.5 (32.3), tomada en sentido vertical del origen de la aleta anal 37.9 (21.7). Mínima profundidad del pedúnculo 15.1 (8.6). Anchura corporal, tomada en la postclavícula 23.3 (13.3), en el origen de la aleta dorsal 27.9 (15.9). Anchura del pedúnculo en el punto de mínima profundidad 5.7 (3.3). Distancia del hocico al origen de la aleta dorsal 77.5 (44.3); al origen de la aleta pectoral 43.7 (25.0); al origen de la aleta pélvica 91 (52.0); al origen de la aleta anal 136 (77.7). Distancia del origen de la aleta pectoral al origen de la aleta pélvica 48 (27.4). Distancia del origen de la aleta pélvica al origen de la aleta anal 48 (27.4). Longitud del lóbulo de la aleta dorsal 27.7 (15.8). Longitud del último radio dorsal 69.5 (39.7). Longitud de la base de la aleta dorsal 27.6 (15.8). Longitud de la base de la aleta anal 27.6 (15.8). Longitud de la aleta pectoral 32.3 (18.5). Longitud de la aleta pélvica 17.0 (9.7). Número de radios dorsales 20, radios anales 21, radios pectorales 18 en la aleta derecha y 17 en la izquierda; radios pélvicos, 9 en la aleta derecha y 8 en la izquierda. Hileras de escamas, en el flanco izquierdo 49 y 50 en el derecho, de la cabeza al origen de la aleta dorsal cerca de 26 hileras, de la parte posterior de la aleta dorsal a la base dorsal cerca de 26, del origen de la aleta dorsal a la línea media ventral aproximadamente 16. Escudetes 18 + 16. Branquispinas ceratobranquiales 59.

Descripción de la especie.—Está representada en las siguientes consideraciones, tablas y figuras.

Holotipo.—USNM 196804. Recolectado en la Bahía Chorrera, Golfo de Panamá, 21-25 ag. de 1960, red de cerco, por la Comisión Interamericana del Atún Tropical.

Paratipos.—Varios especímenes que se encuentran en las colecciones de muchas instituciones.

Distribución geográfica.—De la Bahía de Sechura, Perú, al Puerto de Los Angeles, California (Fig. 2A). En el Perú puede ser la más abundante de las tres especies costaneras del Pacífico, pero en otras partes ocupa el segundo puesto después de *libertate*. El único espécimen de California disponible para examen fué uno de *medirastre* de 192 mm de L. E., aunque un buen número de especímenes de *Opisthonema* aparentemente han sido hallados en aguas californianas (Barnhart, 1936; Radovich, 1960).

Tamaño.—El espécimen más pequeño y el más grande que fueron examinados, midieron 30.0 y 220 mm de L. E.

Sinonimia.—Ya que la presencia de esta especie no ha sido reconocida previamente, cualquier informe no sustentado de *libertate* de las aguas costaneras del Pacífico Oriental puede referirse a él.

Derivación del nombre.—Viene del latín *medius,* que significa mitad o al medio; y *rastrum,* un azadón dentado o rastrillo, ya que esta especie posee un número intermedio de branquispinas con relación a aquellas de las otras dos especies costaneras del Pacífico.

Nombre común.—Arenque de hebra mediano (nombre nuevo).

Opisthonema berlangai especie nueva (Fig. 1B)

Opisthonema libertate (*non* Günther), Gilbert, 1891:449 (parcialmente; especímenes de las Islas Indefatigable (Santa Cruz) y Chatham (San Cristóbal), Islas Galápagos, solamente; "ésta parece ser la especie que figura en la lista de Jordan y Bollman como '*Clupea* sp. (muy joven)' "). Herre, 1936:32 (pequeños especímenes de la Isla Edén, Galápagos). Fowler, 1938:20 y 249 (parcialmente; especímenes de las Islas Galápagos solamente). Hildebrand, 1946:81 (parcialmente; referencia de las de las Islas Galápagos solamente). Peterson, 1956:178 (parcialmente; referencia de las de las Islas Galápagos solamente).

Clupanodon libertatis (*non* Günther), Snodgrass y Heller, 1905:348 (parcialmente; especímenes de la Isla Seymour (Baltra) y de la Bahía Wreck de la Isla Chatham (San Cristóbal), Galápagos solamente).

Opisthonema libertatis (*non* Günther), Regan, 1917b:386 (parcialmente; referencia de las de las Islas Galápagos solamente). Fowler, 1932:3 (especímenes de la Bahía Conway en la Isla Indefatigable (Santa Cruz), Galápagos).

Filialosa libertate (*non* Günther), Fowler, 1944:209 y 482, fig. 31 (parcialmente; descripción; referencia a las de las Islas Galápagos solamente).

Diagnosis.—Las branquispinas ceratobranquiales aumentan en número con el incremento de la longitud corporal hasta cerca de 260 mm de L. E.; en ejemplares de 200 mm de L. E. el número de branquispinas ceratobranquiales es de 63 a 84; este número varía entre 68 y 87 en especímenes de 260 mm de L. E. (el incremento numérico de las branquispinas ceratobranquiales con respecto a la longitud estándar aparece en la Tabla 3 y en la Fig. 12). Distribución geográfica confinada a la vecindad de las Islas Galápagos (Fig. 2A).

Descripción del holotipo [medidas en mm (% de la L. E. en paréntesis)].—Longitud estándar 173. Longitud a la horquilla 183 (105.8). Longitud total 210 (121.4). Longitud de la cabeza, a la clavícula 41.9 (24.2), al margen distal del opérculo 44.8 (25.9). Longitud de la mandíbula superior 17.7 (10.2). Profundidad del maxilar 6.8 (3.9). Anchura interorbitaria 10.4 (6.0). Diámetro del ojo 10.7 (6.2). Longitud del hocico 13.2 (7.6). Longitud postorbitaria de la cabeza, tomada en sentido horizontal 20.3 (11.7), longitud máxima 25.5 (14.7). Profundidad corporal, tomada verticalmente del origen de la aleta dorsal 50.5 (29.2), del origen de la aleta dorsal al origen de la aleta pélvica 51.7 (29.9), tomada en sentido vertical al origen de la aleta anal 35.7 (20.6). Profundidad mínima del pedúnculo 15.2 (8.8). Anchura corporal tomada en la postclavícula 22.1 (12.8), en el origen de la aleta dorsal 22.0 (12.7). Anchura del pedúnculo en el punto de mínima profundidad 6.3 (3.6). Distancia del hocico al origen de la aleta dorsal 75 (43.4); al origen de la aleta pectoral 43.3 (25.0); al origen de la aleta pélvica 83.5 (48.3); al origen de la aleta anal 129 (74.6). Distancia del origen de la aleta pectoral al origen de la aleta pélvica 43.6 (25.2). Distancia del origen de la aleta pélvica al origen de la aleta anal 47.2 (27.3). Longitud del lóbulo de la aleta dorsal 29.3 (16.9). Longitud del último radio dorsal 69.5 (40.2). Longitud de la base de la aleta dorsal 28.6 (16.5). Longitud de la base de la aleta anal 27.0 (15.6). Longitud de la aleta pectoral 30.2 (17.5). Longitud de la aleta pélvica 15.9 (9.2). Número de radios dorsales 20, radios anales 21, radios pectorales en cada aleta 17, radios pélvicos en la aleta izquierda 9, en la derecha 8. Hileras de escamas, en ambos flancos 50 aproximadamente, de la cabeza al origen de la aleta dorsal cerca de 21, de la parte posterior de la aleta dorsal a la base caudal dorsal aproximadamente 28, del origen de la aleta dorsal a la línea media ventral cerca de 15. Escudetes 18 + 17. Branquispinas ceratobranquiales 61.

Descripción de la especie.—Está representada en las siguientes consideraciones, tablas y figuras.

Holotipo.—USNM 196807 (originalmente UCLA W 55-314). Recolectado en el extremo oriente de la bahía situada en la esquina nororiental de la Isla Barrington (Santa Fe), Islas Galápagos, 26 de nov. 1955, envenenamiento con rotenona por A. W. Ebeling y colaboradores.

Paratipos.—Muchos especímenes en las colecciones de varias instituciones.

Distribución geográfica.—Está restringida a la vecindad de las Islas Galápagos y es la única especie de *Opisthonema* que se sabe aparece en las Islas Galápagos. Se conocen registros definitivos provenientes de nueve de estas Islas (Fig. 2A). El registro más distante pertenece a un espécimen capturado cerca de 70 millas al noreste de las Islas Galápagos. Examinamos especímenes capturados en las Islas Galápagos desde 1872 obviando la teoría de que su establecimiento allí se debe a los barcos atuneros al ser utilizados estos peces como carnada viva (esta teoría ha sido sugerida también con respecto a otras especies de "carnada viva").

Tamaño.—El espécimen más pequeño y el más grande que fueron examinados, midieron 23.0 y 260 mm de L. E. respectivamente. El espécimen más grande de *Opisthonema* que haya sido examinado de 281 mm de L. E., 80 branquispinas ceratobranquiales, CAS, obtenido del Acuario Steinhart, cuya localidad de recolección se desconoce, es probablemente de esta especie.

Sinonimia.—Por el hecho de estar confinada esta especie a las Galápagos y aparentemente siendo el único *Opisthonema* que allí se encuentra, se presume que todos los registros previos de *libertate* de las Galápagos se refieren a *berlangai.*

Derivación del nombre.—Es el patronímico de Fray Tomás de Berlanga, a quien se le acredita el descubrimiento de las Islas Galápagos en mayo de 1535 (Slevin, 1959:13).

Nombre común.—Arenque de hebra de las Galápagos (nombre nuevo).

Opisthonema libertate (Günther, 1866) (Fig. 1C)

Meletta libertatis Günther, 1866:603 (localidad tipo, La Libertad, El Salvador; el holotipo se encuentra en el Museo Británico (Historia Natural), no. 1864.1.26.181).

Clupea libertatis, Günther, 1868a:487 (catalogado; "bien relacionado con *C. thrissa*"). Günther, 1868b:433 (descripción original repetida). *Opisthonema libertate,* Jordan y Gilbert, 1883b:622 (especímenes del Pacífico panameño). Jordan, 1885:366 (catalogado de Mazatlán, México, y del Pacífico panameño). Jordan, 1887b:825 (catalogado en la fauna tropical de la costa del Pacífico). Gilbert, 1891:449 (parcialmente, excluyendo los especímenes de las Galápagos). Jordan, *et. al.,* 1895:408 (especímenes de Sinaloa, México). Jordan y Evermann, 1896:433 (descripción; distribución geográfica). Gilbert y Starks, 1904:40 (descripción; especímenes de Panamá; se menciona a *O. oglinum*). Osborn y Nichols, 1916:149 (especímenes de la Bahía Ballenas a Isla Carmen, México). Meek y Hildebrand, 1923:188 (descripción; Punta Chame, Isla Taboga, y Plaza del Mercado de Panamá, en el Pacífico panameño). Jordan, Evermann, y Clark, 1930:44 (lista de especies). Breder, 1936:53 (especímenes de la Isla Pedro Gonzales de las Islas Perlas, Panamá). Barnhart, 1936:15, Fig. 46 ("se ve en San Diego no muy frecuentemente"). Fowler, 1938:20 y 249 (parcialmente; excluyendo la información de las Galápagos). Chapman, 1944:6,

Figs. 5, 10, 12, 15 y 18 (osteología). Nichols y Murphy, 1944:233 (especímenes pequeños de la Isla La Plata, Ecuador, e Isla Gorgona, Colombia). Hildebrand, 1946:81 (parcialmente; descripción; Isla La Plata, Ecuador, y Bahía de Sechura, Perú; excluyendo la información de las Galápagos). Villagómez, 1948:51 (especímenes de Manta, Manabi, Ecuador). Fitch, 1948:134, Fig. 51 (espécimen capturado en San Pedro, California; abunda en el Golfo de California; posible dispersión por medio de barcos atuneros de carnada viva). Clothier, 1950:37, plancha II (osteología; San Pedro y Seal Beach, California). McHugh y Fitch, 1951:493 (distribución; San Pedro, California; Bahía Ballenas, Bahía San Juanico, Bahía Santa María y Bahía Magdalena, Baja California, México). Bini y Tortonese, 1955:159 (especímenes de Chimbote y Mancora, Perú). Peterson, 1956:178 (parcialmente; descripción; Golfo de Nicoya, Costa Rica; excluyendo la información de las Galápagos). Berdegué A., 1956:153, Fig. 133 (descripción; catalogado para el Pacífico mexicano). Morrow, 1957:14 (especímenes de Cabo Blanco y Talara, Perú). Harder, 1958a:370, Fig. 5a, y 1958b:18, Fig. 27 (tracto digestivo y conducto neumático). Radovich, 1960:163 (frente al Muelle Belmont, al sur de Long Beach, California). Fausto, 1961:1, Fig. 1 (tracto digestivo de acuerdo a Harder 1958a:370). Radovich, 1961:18 (catalogado), p. 27 (figura como el arenque de hebra del Pacífico; parcialmente; espécimen del Muelle Belmont, Long Beach, California, 29 mayo 1958; excluyendo el espécimen del Puerto de Los Angeles que es *O. medirastre),* p. 31 (figura como el arenque de hebra del Pacífico; espécimen de Redondo Beach, California, 9 nov. 1959).

Opisthonema libertatis, Evermann y Jenkins, 1891:127 y 134 (Guaymas, Sonora, México; se menciona *O. oglinum*). Regan, 1917b:386 (parcialmente; descripción; excluyendo *C.* (*O.*) *bulleri* de la sinonimia y la información de las Galápagos). Hildebrand, 1925:283 (especímenes de El Triunfo, El Salvador).

Clupanodon libertatis, Snodgrass y Heller, 1905:348 (parcialmente; excluyendo los especímenes de las Galápagos).

Filialosa libertate, Fowler, 1944:209 y 482 (parcialmente; descripción; Playa Muerto, Panamá; excluyendo las referencias del material de las Galápagos).

Diagnosis.—Las branquispinas ceratobranquiales aumentan en número con el incremento correspondiente de la longitud corporal hasta tamaños de más de 200 mm de L. E.; 79 a 110 branquispinas ceratobranquiales en ejemplares de 200 mm de L. E. (el incremento en número de las branquispinas ceratobranquiales con respecto a la longitud estándar aparece en la Tabla 3 y en las Figs. 7, 8 y 9; y la variación geográfica aparece en la Fig. 10A).

Distribución geográfica.—En aguas costaneras del Pacífico Oriental, del Perú a México (Fig. 2A).

Descripción del holotipo [medidas en mm (% de la L. E. en parén-

tesis)].—Longitud estándar 54.4. Longitud de la cabeza al margen distal del opérculo 13.8 (25.4). Profundidad corporal, tomada verticalmente del origen de la aleta dorsal 14.5 (26.7). Longitud del último radio dorsal 18 (33.1). Longitud de la aleta pectoral 8.3 (15.3). Longitud de la aleta pélvica 5.5 (10.1). Número de branquispinas epibranquiales 41, ceratobranquiales 34, hipobranquiales 36, todas en el lado derecho.

Descripción de la especie.—Está representada en las siguientes consideraciones, tablas y figuras.

Holotipo.—BMNH 1864.1.26.181. Recolectado en La Libertad, El Salvador, por Salvin y Dow.

Distribución geográfica.—De Punta Sal y Punta Picos, Perú, a la Bahía Santa Rosalita, en la costa del Pacífico de Baja California, México (Fig. 2A). Es la más abundante de las tres especies de *Opisthonema* de la costa del Pacífico, habiéndose obtenido numerosos registros del Golfo de Panamá, el Golfo de Nicoya y la Bahía Magdalena.

Tamaño.—El espécimen más pequeño y el más grande que fueron examinados, midieron 21.0 y 215 mm de L. E. respectivamente.

Sinonimia.—Exceptuando cuestiones que se refieren específicamente al espécimen tipo, todas las que se refieran a *libertate* son objeto de discusión ya que pueden aplicarse a cualquiera de las tres especies costaneras del Pacífico, a menos que los especímenes a los cuales se refieren hayan sido reexaminados con pleno conocimiento de la existencia de las tres especies.

Derivación del nombre.—Nombrada por La Libertad, puerto de El Salvador, localidad tipo.

Nombre común.—Arenque de hebra de cuerpo profundo (en vez de arenque de hebra del Pacífico).

Opisthonema bulleri (Regan, 1904) (Fig. 1D)

Clupea (*Opisthonema*) *Bulleri* Regan, 1904:255 (parcialmente; localidad tipo Las Peñas (Puerto Vallarta), Jalisco, México; lectotipo 77 mm de L. E. en el Museo Británico (Historia Natural) no. 1892.9.5. 131; no incluye un cotipo previo de 110 mm de L. E., que es *O. medirastre*).

Opisthonema libertatis (*non* Günther), Regan, 1917b:386 (parcialmente; información sinonímica a *bulleri* solamente).

Designación del lectotipo.—De los dos especímenes, de 77 y 110 mm de L. E. designados originalmente como cotipos de *bulleri* por Regan, el espécimen más pequeño, el de 77 mm, se designa desde aquí como el lectotipo de *bulleri*. El ejemplar más grande, el de 110 mm, es *Opisthonema medirastre* (posee 40 branquispinas ceratobranquiales).

Diagnosis.—Las branquispinas ceratobranquiales aumentan en número con el correspondiente incremento de la longitud corporal hasta cerca de 140 a 170 mm de L. E.; 26 a 36 branquispinas ceratobranquiales en

especímenes de 170 a 200 mm de L. E. (el incremento en el número de branquispinas ceratobranquiales con respecto a la longitud estándar aparece en la Tabla 3 y en las Figs. 7, 8 y 9; la muy pequeña indicación de variación geográfica se muestra en la Fig. 10C).

Distribución geográfica.—En aguas costaneras del Pacífico Oriental, del Perú a México (Fig. 2A).

Descripción del lectotipo.—Longitud estándar 77 mm. Branquispinas ceratobranquiales 25.

Descripción de la especie.—Está representada en las siguientes consideraciones, tablas y figuras.

Lectotipo.—BMNH 1892.9.5.131. Recolectado en Las Peñas (Puerto Vallarta), Jalisco, México, por el Dr. Buller.

Distribución geográfica.—Desde Punta Sal y Punta Picos, Peru, hasta Mazatlán, Sinaloa, México (Fig. 2A). Aparentemente es la menos abundante de las tres especies costaneras del Pacífico; nuestras recolecciones más numerosas provienen del Golfo de Panamá y del Golfo de Tehuantepec.

Sinonimia.—Cuando describió a *bulleri,* Regan (1904:355) aparentemente pasó por alto la entonces bien conocida *libertate* de Günther, ya que no comparó a *bulleri* con aquella especie, pero comparó sucintamente (e incorrectamente) *bulleri* con la especie del Atlántico *Clupea thrissa* [= *O. oglinum*]. La descripción original de *bulleri* hecha por Regan, como *"Clupea (Opisthonema) Bulleri",* ha sido pasada por alto en listas y sinonimias ictiológicas subsiguientes, con una excepción. Aparece catalogada como sinónimo de *Opisthonema libertatis (sic)*, sin explicación alguna, en una de las últimas revisiones de Regan sobre peces clupeidos (1917b:386).

Derivación del nombre.—Es el patronímico del Dr. Buller quien hizo las recolecciones.

Nombre común.—Arenque de hebra sutil (nombre nuevo).

Opisthonema oglinum (LeSueur, 1818)

Clupea thrissa (*non* Linnaeus), Linnaeus, 1758:318 (parcialmente; referencia a Browne solamente). Broussonet, 1782: ? (parcialmente; referencia al material del Atlántico solamente). Günther, 1868:432 (parcialmente; excluyendo de las citaciones sinonímicas las de Osbeck y Agassiz; descripción; especímenes catalogados de Barbados, Dominica, Puerto Cabello, Trinidad, Granada, Santo Domingo, Cuba, Jamaica).

Megalops oglina LeSueur, 1818:359 (descripción; localidad tipo Newport, Rhode Island; aparentemente el espécimen tipo no se conservó; se menciona *Clupea thrissa* de Bloch).

Megalops notata LeSueur, 1818:361 (descripción; localidad tipo Pigeon, Isla Guadalupe; no se conservó el espécimen tipo; se menciona *C. thrissa* de Bloch; se usaron los caracteres de variación intraespecíficos entonces conocidos para distinguir a este espécimen de *oglina* en la p. 359 de la misma publicación).

Chatoessus signifer DeKay, 1842:264, plancha 41, Fig. 132 (localidad tipo New York; el espécimen tipo si acaso fué preservado originalmente, es probable que haya sido destruído subsecuentemente; se menciona *C. thrissa* de Bloch y *Megalops oglina* de LeSueur; nombre común que se le dió, "arenque de hebra manchado"). Baird, 1855:349 (Great Egg Harbor Bay, New Jersey).

Meletta thrissa Valenciennes en Cuvier y Valenciennes, 1847:380 (descripción; localidades tipos New York, Santo Domingo, Guadalupe, Martinica y Brasil; los nombres de las especies relacionadas se discuten). Bertin, 1940:277 (14 especímenes en el Museo de París se catalogan como paratipos y como sinómino de *Opisthonema oglinum*).

? *Alausa striata* Valenciennes en Cuvier y Valenciennes, 1847:429 (descripción; localidades tipo, Islas Guadalupe y Bahía, Brasil; se dice que probablemente es la misma especie que *Clupea arcuata* Jenyns). Storey, 1938:51 (los tipos de Guadalupe han desaparecido aparentemente del Museo de París; los tipos de Bahía fueron examinados por el Dr. Chabanaud; éstos no están comprendidos en el género *Harengula* como fueron clasificados por Jordan y Evermann, 1896:431). Bertin, 1940:289 (2 especímenes, de 190 y 220 mm de Bahía, catalogados como paratipos y sinonimizados con *Opisthonema oglinum*). Bertin, 1941:24 (en los dos especímenes tipo el último radio dorsal prolongado está roto).

Chaetoessus eumorphus Gosse, 1851:290 (descripción; localidad tipo, Jamaica; aparentemente el espécimen tipo no se conservó).

Opisthonema thrissa (*non* Linnaeus), Gill, 1861:37 (designa a *"Opisthonema thrissa* Gill" como especie tipo del nuevo género *Opisthonema).* Gill, 1873:33 (distribución geográfica y nombres comunes). Goode, 1877:293 (catalogada de Bermuda). Jordan y Gilbert, 1879:385 (especímenes de Beaufort Harbor, North Carolina). Goode, 1879:119 (catalogada del oriente de Florida). Bean, 1880:108 (espécimen de la costa oriental de Virginia). Goode y Bean, 1882:239 (catalogada del Golfo de México). Jordan y Gilbert, 1882:247 (especímenes de Pensacola, Florida). Jordan y Gilbert, 1882b:268 (descripción; "se dice que la carne es a veces venenosa"). Jordan y Gilbert, 1883a:574 (nótese que *thrissa* ha sido referida como *Clupanodon* por Lacépède en 1803).

? *Opisthonema thrissa* (*non* Linnaeus), Goode y Bean, 1879:151 (un espécimen de 5½ pulgadas de longitud de Pensacola, Florida, USNM 21462, con D.12 y A.28; cuentas merísticas o identidad probablemente incorrectas).

Opisthonemus thrissa (*non* Linnaeus), Poey, 1881:343 (Porto Rico; *fide* Evermann y Marsh, 1902-86).

Opisthonema oglina, Bean y Dressel, 1884:169 (especímenes de Jamaica). Goode y Bean, 1885:195 y 206 (reconocimiento de la especie Atlántica de *Opisthonema;* restricción de *Clupea thrissa* Linnaeus a especie del Indo-Pacífico).

Opisthonema oglinum, Jordan, 1886a:26 (catalogada de Beaufort, North Carolina). Jordan, 1886b:33 (recolectada en Habana, Cuba).

Jordan, 1887a:561 (catalogada de las Indias Occidentales). Jordan, 1887b:824 (catalogada para la fauna costera de los estados del sur de los Estados Unidos, que bordean el Atlántico y los del Golfo de México y las Indias Occidentales; nota sobre la restricción de *Clupea thrissa* Linnaeus). Jordan, 1890:645 (espécimen de Port Castries, Santa Lucía). Bean, 1891:93 (especímenes de Cape Charles City, Virginia). Jordan, 1891:314 (especímenes de Bahía, Brasil). Jordan y Evermann, 1896:432 (descripción; distribución geográfica). Evermann y Marsh, 1902:86 (descripción; Mercado de San Juan, Palo Seco, Mayaguez; Guanica, Hucares, Isabel Segunda, Fajardo y San Gerónimo, Porto Rico). Fowler, 1911a: (catalogada de Maryland y New Jersey). Fowler, 1911b: (especímenes de New Jersey, Santo Domingo, Jamaica, Puerto Rico, Isla Santa Cruz y Brasil. Nichols, 1912:182 ("común en el mercado de La Habana", Cuba). Regan, 1917a:308 (referencia). Regan, 1917b:385 (descripción; distribución geográfica). Nichols, 1921:22 (catalogada, Turk Islands, Bahamas). Meek y Hildebrand, 1923:187 (descripción; Mindi Cut, Mercado de Colón, Fox Bay, y Porto Bello, Atlántico panameño). Hildebrand y Schroeder, 1928:101 (descripción; alimento, utilización; York River, Buckroe Beach, y Lynnhaven Roads, Virginia). Jordan, Evermann y Clark, 1930:44 (en la lista de especies). MacCoy, 1931:21 (espécimen de Chatham, Massachusetts). Breder, 1938:28 (catalogada, Puerto de New York). Storey, 1938:12, Fig. 5 (fotografía de un espécimen hecho transparente y teñido, de Sanibel, Florida). Fowler, 1941:134 (referencias del Brasil). Campos, 1942:191, plancha III, Figs. 7 y 8 (descripción; especímenes de São Paulo, Ilha S. Sebastião, Río de Janeiro, y Santos, Brasil). Fowler, 1944:434 y 457 (catalogada de las Islas Bahamas y del Atlántico panameño). Fowler, 1945:164 y 266 (lista de especímenes de South Carolina y Florida; la sinonimia contiene varios errores). Bigelow y Schroeder, 1953:112, Fig. 49 (descripción; su existencia en el Golfo de Maine). Springer, 1957:169 (comportamiento de agregación; Content Key, Florida). Harder, 1958b:18, Fig. 28 (tracto digestivo y conducto neumático). Fausto, 1961:3, Figs. 2-4 (tracto digestivo y conducto neumático). Tabb y Manning, 1961:607 (registrados del norte de Florida Bay, Florida).

Clupanodon oglinum, Fowler, 1906:102 (descripción; New Jersey.

Diagnosis.—Las branquispinas ceratobranquiales aumentan en número con el incremento en la longitud corporal hasta cerca de los 120 mm de L. E.; en especímenes de 120 a 230 mm de L. E.; de 29 a 47 branquispinas ceratobranquiales (el incremento en el número de branquispinas ceratobranquiales con respecto a la longitud estándar aparece en la Tabla 3; esta relación y la variación geográfica se muestra en la Fig. 13). Su alcance se extiende por todo el Atlántico occidental del Brasil al Golfo de Maine, en las Indias Occidentales y Bermuda (Fig. 2B).

Descripción del holotipo.—Véase la descripción original de LeSueur (1818:359).

Descripción de la especie.—Está representada en las siguientes consideraciones, tablas y figuras.

Holotipo.—Recolectado en Newport, Rhode Island. Desconocemos la posibilidad de que el holotipo haya sido preservado originalmente o su destino subsecuente.

Distribución geográfica.—Se conoce del Golfo de Maine (MacCoy, 1931:21), Bermuda, y por todas las Indias Occidentales a Florianopolis, Ilho de Argentina, Santa Catarina, Brasil (extensión sureña del alcance previamente publicado, Fig. 2B). El espécimen más norteño que ha sido examinado es el de Hampton Roads, Virginia.

Tamaño.—El espécimen más pequeño y el más grande que fueron examinados midieron 41.6 y 233 mm de L. E. respectivamente.

Sinonimia.—Desde tiempo atrás el uso del nombre *Clupea thrissa* Linnaeus para designar la especie atlántica de *Opisthonema* fué promulgado por la referencia que Linnaeus hace a este nombre en un registro jamaicano (1758:318) y a dos especímenes de Carolina (1766:524). Goode y Bean (1885:195 y 206) examinaron la colección de Linnaeus en Londres, expusieron los errores encontrados en los informes de Linnaeus, detallaron la necesidad de restringir el nombre *thrissa* a una especie asiática, y reconocieron a *Megalops oglina* de LeSueur como nombre apropiado para el *Opisthonema* del Atlántico. Jordan (1887b:824) condensó y clarificó este problema. *Clupea thrissa* Linnaeus se considera ahora como la especie tipo del género *Clupanodon* Lacépède 1803, un género dorsomátido que habita las costas y ríos de la China y del Japón (Regan, 1917a:308).

Derivación del nombre.—"El nombre no tiene explicación con excepción de la palabra *ogle,* en alusión a los ojos grandes" (Jordan y Evermann, 1896:432).

Nombre común.—Arenque de hebra del Atlántico.

Opisthonema palosverdensis David 1943 (especie fósil)

Opisthonema palosverdensis fué descrita como especie nueva por David (1943:84, Fig. 14) de un espécimen hallado en una formación del Mioceno en Palos Verdes Hills, Los Angeles County, California. El espécimen (150 + 35 = 185 mm de longitud, No. 10101 Calif. Inst. Technol. Coll. Vert. Paleont.) puede asociarse con los clupeidos principalmente por los escudetes en la línea media ventral. La interpretación de la aleta dorsal hecha por David fué utilizada para asociar el espécimen con el género *Opisthonema:* "el último radio evidentemente alargado en forma de un filamento largo, visible en aquellas regiones en donde las partículas pétreas no han sido rotas; este radio está oprimido fuera de su sitio y se recarga hacia atrás, su base extendiéndose debajo de la base de los radios que le preceden". Si esta interpretación no es correcta, este fósil mal podría identificarse como *Opisthonema.* Si es correcta, la asociación genérica con *Dorosoma* Rafinesque también debe entrar en consideración. La cabeza y la aleta caudal largas que aparecen en el dibujo de este espécimen, no se ase-

mejan a ninguna de las especies recientes de *Dorosoma* u *Opisthonema*. La inserción posterior de la aleta pélvica (debajo del extremo posterior de la aleta dorsal) y la estructura grande de la mandíbula se asemejan más a *Opisthonema* que a *Dorosoma*. Los caracteres merísticos semejantes son:

	Espécimen fósil	*Opisthonema*	*Dorosoma*
Radios dorsales	17	17-22	9-14
Radios anales	por lo menos 25	19-25	22-38
Escudetes ventrales	17+12 a 14	17-19+14-17	15-20+9-14
Vértebras	41 ó 42	44-49	43-51

COMPARACION DE ESPECIES

La combinación de dos características se usa para diferenciar las cinco especies: 1) la distribución geográfica y 2) el número de branquispinas con relación a la longitud del pez. Se encuentran cuatro especies en el Pacífico Oriental: *berlangai* confinada a las Islas Galápagos, y *libertate, medirastre* y *bulleri,* que ocurren simpátricamente en aguas costaneras desde el Perú hasta México (Fig. 2A); *oglinum* se presenta en el Atlántico occidental (Fig. 2B). Colocando las especies en orden del incremento en el complemento de branquispinas, tenemos: *bulleri, oglinum, medirastre, berlangai* y *libertate.* Las tres especies simpátricas del Pacífico pueden diferenciarse entre sí por medio de esta característica. Los complementos de branquispinas de las geográficamente aisladas *oglinum* y *berlangai* se sobreponen a aquellos de las otras especies.

También se examinó un número apreciable de otras características. Aunque algunas de éstas muestran diferencias promediales o modales interespecíficos, todas tienen algún grado de variación intraespecífica. Además el alcance de estas características para cada especie se sobrepone (generalmente en forma apreciable) al alcance para el resto de las especies. Por su valor limitado en la diferenciación de las especies, no se presenta un análisis profundo de estas características. Los límites y valores promedios de ocho caracteres merísticos se dan en la Tabla 1 y los límites de seis caracteres morfométricos aparecen en la Tabla 2. La inspección de estas tablas indicará el grado del traslapo de valores entre las especies como también las pequeñas diferencias que ocurren en los valores promediales de los caracteres merísticos.

Antes de pasar a otro tema, debemos hacer tres observaciones. 1) El dimorfismo sexual fué aparente en tres caracteres—algunas hembras tienden a tener cuerpos ligeramente más profundos y aletas pectorales y pélvicas más cortas que los machos de la misma recolección. 2) La variación geográfica fué insignificante en relación con los caracteres merísticos (con excepción de las branquispinas), pero se pronuncia en dos caracteres morfométricos—los especímenes de *libertate y medirastre* de México tienen la cabeza más corta y cuerpo menos profundo que aquellos de Costa Rica y Panamá. Las tendencias morfométricas de esta naturaleza fueron resumidas por Barlow (1961). 3) La relación del número de branquispinas es contraria a lo que se espera, en vista de la generalización de que el número

de elementos merísticos es progresivamente más grande de aguas templadas a aguas más frías (discutido por Barlow, 1961). Las especies *libertate* y *medirastre* poseen menor número de branquispinas en las aguas más frías de las regiones norteñas que de las aguas más templadas de regiones hacia el sur. Teorizamos diciendo que, para las especies anteriores, mientras la longitud de la cabeza depende de las condiciones del medio ambiente, no ocurre lo mismo con el número de branquispinas, ya que éste depende de la longitud de la cabeza—cuanto más corta sea la cabeza, menor será el número de branquispinas. McHugh (1954:147) aludió a una relación similar en el arenque del Pacífico.

Antes de discutir la relación entre el número de branquispinas y el tamaño del pez, es necesario definir la medida de la longitud estándar y describir brevemente la morfología de las branquispinas.

La medida de la longitud estándar

La longitud estándar se mide desde la punta del hocico hasta la parte terminal de los huesos hipúricos medios (base caudal). En especímenes más pequeños (de menos de 80 mm de L. E.), la base caudal puede verse más fácilmente al trasluz. En especímenes más grandes, la musculatura, el tejido conjuntivo y las escamas que se extienden hasta la aleta caudal, obscurecen la base caudal. La técnica frecuentemente usada de indicar la localización de la base caudal—la línea vertical de flexión que aparece cuando la aleta caudal es doblada hacia un lado—no puede aplicarse a *Opisthonema*. La línea de flexión en este género, aparece anteriormente (cerca de 1.5% de la L. E.) a la base caudal, especialmente en peces grandes. Esto ocurre probablemente porque los radios caudales medios de los lóbulos dorsal y ventral desarrollan bases engrosadas y alargadas que descansan en ambos lados de los hipúricos medios y se extienden anteriormente hasta casi el urostilo; las bases de los radios principales más dorsales y ventrales también se extienden sobre los huesos hipúricos. Estas bases radiales extendidas dan una rigidez a la cola que se refleja en una línea de flexión que aparece más anteriormente que en muchos otros peces.

Morfología y cuenta de las branquispinas

El primer arco branquial de un espécimen grande se ilustra en la Fig. 3A; las porciones osificadas del primer arco branquial en un espécimen pequeño son ilustradas en la Fig. 3B.

Las branquispinas tanto epibranquiales como ceratobranquiales se diferencian fácilmente en el ángulo que existe entre los miembros superiores e inferiores en especímenes pequeños (hasta cerca de 120 mm de L. E.) por medio de la configuración de las bases de las branquispinas localizadas en este punto de unión (Fig. 3B). En especímenes grandes este punto de unión se distiende dorsolateralmente con la distorsión consecuencial de las bases de las branquispinas en esta área, haciendo su distinción más difícil.

Una branquispina situada en el punto de unión de los segmentos ceratobranquial e hipobranquial; se designa arbitrariamente como *ceratobranquial,* cuando la mayor parte de su base está colocada posteriormente a la línea de unión, e *hipobranquial,* cuando su base se sitúa anteriormente a

esta línea. La mencionada línea de unión se reconoce por una línea escasamente oblicua, clara y pigmentada situada en el centro de un área de tejido angosto y relativamente traslúcida. La línea oblicua tiene diversos colores como crema, amarillo o anaranjado, y aparentemente está compuesta de tejido graso. El tejido traslúcido a ambos lados de la línea se compone de cartílago proveniente de la porción terminal anterior del hueso ceratobranquial y la porción terminal posterior del hueso hipobranquial (Fig. 4). Esta línea puede verse fácilmente en la mayoría de los especímenes preservados, pero en otros a causa de pigmentación u opacidad, una porción de piel situada en la vecindad de la unión debe ser removida para que la línea se destaque.

Los tamaños relativos de las diferentes branquispinas y su posición relativa en el arco branquial aparecen en la Fig. 5. Con el crecimiento contínuo del pez, algunas branquispinas forman expansiones laterales que pueden dificultar la cuenta de las branquispinas. Estas branquispinas agrandadas son más numerosas en el segmento epibranquial, más numerosas en los ejemplares grandes que en los pequeños, siendo también más numerosas en *libertate* que en las otras especies.

La variación bilateral es insignificante y puede ser despreciada.

Ontogenia de las branquispinas

El número de branquispinas aumenta con el incremento en la longitud corporal. Este aumento en el número de branquispinas continúa hasta cerca de los 120 mm de L. E. en *oglinum,* entre 140 y 170 mm de L. E. en *bulleri,* y más de 200 mm de L. E. en las otras tres especies. Después de la formación inicial de las branquispinas en los tres segmentos, cosa que ocurre alrededor de los 200 mm de L. E., las branquispinas siguen formándose únicamente en la porción terminal anterior de los segmentos epibranquial e hipobranquial, justificando el incremento en el número de branquispinas en estos segmentos. Sin embargo, el número de branquispinas también aumenta en el segmento ceratobranquial. Esto ocurre porque las branquispinas se insertan no en los huesos sino flojamente en el tejido conjuntivo que los cubre. Como la porción terminal anterior del hueso ceratobranquial crece anteriormente, empuja al hueso hipobranquial hacia adelante, resultando en que la parte terminal anterior del hueso ceratobranquial viene a quedar debajo de las branquispinas que previamente se encontraban sobre la porción terminal posterior del hueso hipobranquial.

La relación que existe entre el número total de branquispinas en el primer arco y la longitud estándar aparece en la Fig. 6. Las tres especies costaneras del Pacífico pueden diferenciarse entre sí por esta característica. En especímenes de más de 150 mm de L. E. *libertate* tiene el número total de branquispinas más alto (cerca de 290 a 353), *medirastre* un número intermedio (aproximadamente 180 a 256), y *bulleri* el número más bajo (cerca de 103 a 128); *berlangai* (con cerca de 215 a 284 branquispinas) traslapa la región de alcance de *medirastre* y a tamaños más pequeños traslapa la región de alcance de *libertate; oglinum* (con aproximadamente

125 a 157 branquispinas) se sitúa en un punto intermedio entre *medirastre* y *bulleri*.

El número de branquispinas en cada uno de los tres segmentos del arco branquial tiene la misma relación interespecífica con respecto a la longitud estándar así como también con el número total de branquispinas. Los siguientes límites numéricos aproximados de branquispinas epibranquiales, ceratobranquiales e hipobranquiales se refieren a especímenes de más de 150 mm de L. E.:

	Epibranquiales	Ceratobranquiales	Hipobranquiales
libertate	110-149	71-107	90-117
medirastre	70-99	50-68	60-88
bulleri	35-47	28-35	37-48
berlangai	75-117	58-80	75-91
oglinum	43-60	30-46	42-61

Análisis de las branquispinas ceratobranquiales

El número de branquispinas ceratobranquiales separa completamente las tres especies simpátricas costaneras del Pacífico y es el criterio preferencial para las diferenciación interespecífica por las tres razones siguientes: 1) son relativamente pocas, con un máximo de 107 ceratobranquiales en comparación con un máximo total de 353 branquispinas; 2) las branquispinas anteriores de los segmentos epibranquial e hipobranquial son pequeñas y algo inaparentes; 3) la porción ceratobranquial se hace visible en su totalidad simplemente al levantar el opérculo.

La adecuada determinación de la variación de las branquispinas para cada especie requiere: un elevado número de especímenes (para dar razón de la variación intraespecífica), series completas del tamaño de los especímenes (para la variación ontogénica), y especímenes capturados en toda el área en que aparecen (para la variación geográfica). Las colecciones que nos han sido asequibles se han aproximado a estos requisitos.

Hemos determinado que para las cuatro especies más diseminadas (*libertate, medirastre, bulleri* y *oglinum*) existe variación geográfica en la relación que hay entre el número de branquispinas y la longitud estándar.

Lo más importante en la distinción de las especies es separar las tres que coexisten en las aguas costeras del Pacífico Oriental. Las otras dos especies pueden entonces ser comparadas ya que están aisladas geográficamente de éstas y entre sí mismas.

Las relaciones que existen entre el número de las branquispinas ceratobranquiales y la longitud estándar están graficadas por medio de puntos en la Fig. 7, para todos los especímenes de *libertate, medirastre,* y *bulleri* del Perú, Panamá y Costa Rica (incluyendo un espécimen de *libertate* de Colombia y tres de El Salvador). Por el hecho de poseer un número bajo de branquispinas, todos los especímenes de *bulleri* pueden distinguirse fácilmente, así como también los especímenes grandes de *libertate* y *medirastre* (de más de 90 mm de L. E. aproximadamente). El traslapo en los perfiles (ver página 176) para los especímenes pequeños de *libertate* y *medirastre*

resulta de la inclusión en esta misma figura de especímenes de áreas diferentes. Los especímenes pequeños (de menos de 60 mm de L. E.), del Perú de *medirastre* y posiblemente de *libertate,* en promedio vienen a tener un mayor número de branquispinas ceratobranquiales que los especímenes pequeños de estas especies de Panamá. Los especímenes pequeños de *medirastre y libertate* de Costa Rica tienen, en promedio, menor número de branquispinas ceratobranquiales que aquellos de Panamá. Consecuentemente, con respecto a estos especímenes pequeños, *medirastre* del Perú tiene un complemento de branquispinas similar a aquél de *libertate* de Costa Rica.

En las cinco especies el número de branquispinas aumenta con el incremento en la longitud corporal hasta valores máximos que difieren interespecíficamente como ha sido anotado previamente. Cada especie tiene una forma diferente y distintiva de incremento en el número de branquispinas con el aumento en la longitud estándar. El incremento en el número de branquispinas podría expresarse como una regresión curvilínea de número a un tamaño dado, pero esta curva podría no ser tan pertinente como su variación. Esta última nos permitiría saber qué límites numéricos de branquispinas se esperarían obtener en las cinco especies a diferentes longitudes.

El cálculo de los límites de confianza para las regresiones podría ser dificultoso ya que 1) la relación es curvilínea y 2) la variación en el número de branquispinas ceratobranquiales aumenta con el incremento de la longitud. La técnica más práctica es graficar el número de branquispinas ceratobranquiales contra la longitud estándar y circunvalar estos puntos por medio de una línea continua a manera de perímetro. Esta línea perimétrica se denomina, para efectos del presente estudio, el *perfil* de las branquispinas ceratobranquiales y representa la forma en que el número de branquispinas ceratobranquiales aumenta con el incremento en la longitud estándar. Los perfiles caracterizan a cada especie, aunque, como se hace notar más adelante, las separaciones entre las especies no son muy claras para los tamaños menores.

El número de branquispinas ceratobranquiales se grafica contra la longitud estándar en la Fig. 8 para todos los especímenes de *libertate, medirastre* y *bulleri* del sur de México (Chiapas a Nayarit) y del sureste de Baja California (Cabo San Lucas a Bahía Concepción).

El número de branquispinas ceratobranquiales se grafica contra la longitud estándar en la Fig. 9 para todos los especímenes de *libertate, medirestre* y *bulleri* del norte continental de México (Sinaloa y Sonora), del noroeste de Baja California (Bahía de San Luis Gonzaga a San Felipe), y del occidente de Baja California (de la Bahía Almejas al norte, incluyendo un espécimen de *medirastre* de Los Angeles, California).

Por conveniencia, las áreas geográficas que se consideran en la Fig. 8 se referirán en el texto y en las figuras como del sur de México y aquellas de la Fig. 9 como del norte de México. En la separación de estas dos áreas

no fué nuestra intención el sugerir una estricta descontinuidad zoogeográfica entre ellas o una similitud ambiental en cada una de ellas. Sin embargo, las relaciones existentes entre el número de branquispinas ceratobranquiales y la longitud estándar generalmente son similares en cada una de las áreas, siendo evidente la variación geográfica entre ellas. Un número adecuado de especímenes de todos los tamaños y especies, y de todas las áreas de México, probablemente revelaría un clin (gradación de diferencias morfológicas dentro de una especie en un área geográfica determinada) en el que el número de branquispinas decrece de norte a sur, poseyendo los especímenes del sureste de Baja California, en promedio, un número ligeramente mayor de branquispinas que los especímenes de una latitud equivalente en el continente (Sonora).

El traslapo en los límites de las cuentas de branquispinas en especímenes pequeños de *bulleri* y *medirastre* en la Fig. 8 ocurre porque los especímenes pequeños de *bulleri* del Golfo de Tehuantepec fueron graficados junto con ejemplares pequeños de *medirastre* provenientes de la Bahía Banderas hacia el norte. Intraespecíficamente los especímenes sureños de Tehuantepec tienen, en promedio, un número de branquispinas ligeramente mayor que aquellos de la Bahía Banderas. Graficando especímenes pequeños de áreas geográficas más restringidas se tiende a eliminar este traslapo, como se mostrará después.

La variación geográfica en el número de branquispinas se ilustra separadamente para cada especie en la Fig. 10 (A, B y C) superponiendo los perfiles de cada área.

Para *libertate* (Fig. 10A), los límites inferiores de su región de alcance para cada área demuestran un clin en el número de branquispinas que decrece de sur a norte. Hay una consistencia menor en los límites superiores de los perfiles de especímenes grandes, siendo así que los límites superiores del grupo del norte de México están colocados más arriba que los del grupo del sur de México. Este es probablemente un artefacto causado por muestras de tamaño desiguales en estos dos grupos. El perfil del grupo del sur de México fué estimado de sólo diez especímenes de más de 140 mm de L. E., y probablemente no representa la variación verdadera en los grupos a tamaños mayores. El perfil del grupo del norte de México se basa en un número mayor de especímenes grandes y de variación relativamente grande. Este último incluía una recolección de 93 especímenes de 167 a 200 mm de L. E. del norte del Golfo de California. En dos de éstos, el número de branquispinas ceratobranquiales fué de 82 en el de 197 mm y 106 en el de 200 mm.

Para *medirastre* (Fig. 10B), es bien aparente que el clin decrece de sur a norte. El perfil del grupo Perú-Panamá-Costa Rica se vuelve asintótico a tamaños grandes, lo cual indica que no hay un incremento posterior en el número de branquispinas ceratobranquiales después de cerca de los 180 mm de L. E. En los dos grupos de México, el número de branquispinas

ceratobranquiales aparentemente continúa aumentando después de una longitud estándar de 180 mm.

Para *bulleri* (Fig. 10C), especie con un complemento de branquispinas relativamente bajo, el clin geográfico en el número de branquispinas no es aparente. Sin embargo, el perfil correspondiente a los ejemplares grandes de México se basa en sólo cinco especímenes, y entonces hay la posibilidad de que este clin exista.

Los perfiles de cada especie de todas las áreas fueron combinados y se presentan como un perfil individual para cada especie en la Fig. 10D. Estos perfiles incluyen los valores máximo y mínimo de cada especie. Demuestran, naturalmente, más traslapo (especialmente a tamaños pequeños) entre las especies que los perfiles geográficos diferenciados. El perfil característico de cada especie representa un modelo incremental específico en el número de branquispinas ceratobranquiales para esa especie. Este modelo caracteriza determinada especie.

La Fig. 11A es una ilustración de la variación intraespecífica y de la hasta ahora discreta separación interespecífica de los especímenes pequeños provenientes de la misma área. Se basa en una sola recolección de Sonora, México (UCLA, W50-40) que contenía 196 especímenes de *Opisthonema* y que representa dos especies:

medirastre, 109 especímenes, límite 45.0-70.5 mm, media 59.9 mm.
libertate, 87 especímenes, límites 45.0-64.0 mm, media 53.8 mm.

A estos tamaños más pequeños la variación intraespecífica total es menor que a tamaños mayores, pero el grado de separación entre las especies también es menor.

Una situación similar a aquella de la recolección de Sonora se presenta en la Fig. 11B para 557 especímenes provenientes de 19 recolecciones hechas en el Golfo de Nicoya, Costa Rica, de 1952 a 1960, que representan tres especies:

libertate, 412 especímenes, límites 21.0-85.0 mm.
medirastre, 142 especímenes, límites 30.6-65.0 mm.
bulleri, 3 especímenes, límites 30.0-86.0 mm.

La separación positiva de *libertate* y *medirastre,* puede ser llevada a cabo hasta cerca de los 35 mm de L. E.; a longitudes inferiores a ésta la diferenciación es menos definida. Los especímenes de *bulleri* son fácilmente reconocibles.

Para *berlangai,* especie aislada de las Islas Galápagos, el número de branquispinas ceratobranquiales se grafica contra la longitud estándar en la Fig. 12; los perfiles correspondientes a las tres especies costaneras del Pacífico (tomadas de la Fig. 10D) también se indican. El perfil que corresponde a *berlangai* es bastante diferente de aquellos de las otras tres especies; a tamaños menores existe bastante traslapo con *libertate,* a tamaños intermedios el mayor traslapo es con *medirastre,* y a tamaños mayores llena el vacío entre estas dos especies.

Para *oglinum,* especie ampliamente distribuída en el Atlántico occiden-

tal, el número de branquispinas ceratobranquiales se grafica contra la longitud estándar en la Fig. 13; los perfiles de las tres especies costaneras del Pacífico (tomadas de la Fig. 10D) también se indican. El perfil correspondiente a *oglinum* es marcadamente diferente del de las otras tres especies. Traslapo al de *libertate* para tamaños hasta cerca de 100 mm de L. E., al de *medirastre* hasta cerca de 170 mm, y al de *bulleri* a más de aproximadamente 60 mm; también llena el vacío existente entre *medirastre* y *bulleri*. La característica más marcada del perfil de *oglinum* es el tamaño corporal relativamente pequeño el cual llega a ser asintótico. Cierta variación geográfica existe en *oglinum*, y cuatro grupos geográficos diferentes pueden distinguirse en la Fig. 13. Especímenes de *oglinum* de las aguas costeras de los Estados Unidos, México, Guayana Británica y Surinam, y del Brasil, con límites en el número de branquispinas generalmente similares, se grafican conjuntamente; este grupo tiene, en promedio, el menor número de branquispinas. Los especímenes de *oglinum* de la costa atlántica de Panamá generalmente son similares a especímenes de aguas insulares (alrededores de Bermuda y las Indias Occidentales), y ambos grupos tienen, en promedio, un número más alto de branquispinas ceratobranquiales que los especímenes de otras áreas. Pese a los vacíos en la representación distribucional de nuestras muestras de *oglinum*, los datos son suficientes para mostrar (en éste y en todos los otros caracteres examinados) que nos estamos refiriendo a una sola especie atlántica y que la especiación que ha ocurrido en el Pacífico no se ha llevado a cabo en el Atlántico.

Los perfiles característicos de las cinco especies se comparan en la Fig. 14.

Clave para las especies

Tres aspectos se usan para la identificación de los especímenes: lugar de captura, longitud estándar, y número de branquispinas ceratobranquiales. Ya que la relación branquispinas-longitud estándar es ontogénicamente variable, una simple llave dicotómica no puede ser usada. La Tabla 3 sirve de clave para la identificación de las especies. Por ejemplo, si un espécimen de Panamá tiene 35 branquispinas ceratobranquiales y una longitud estándar de 75 mm, es *medirastre*. Un espécimen del norte de México con 29 branquispinas ceratobranquiales y 120 mm de L. E. es *bulleri*. Se presume que los especímenes de las Galápagos y del Atlántico sean *berlangai* y *oglinum* respectivamente.

Existen traslapos en los límites de la longitud estándar a cierto número bajo de branquispinas ceratobranquiales—especialmente en *libertate* y *medirastre* de las áreas sureñas. Como fué discutido previamente, éste es el resultado de combinar valores de extensas áreas geográficas. Un espécimen que justamente cae en la zona de traslapo debe ser identificado por la comparación de una serie de especímenes de las dos especies en cuestión de esa área en particular. Véase la Fig. 11 para ejemplo de esta última identificación positiva de especímenes de tamaños pequeños.

Otros estudios sobre las branquispinas de los clupeidos

Cierto número de referencias se refieren al incremento en el número de branquispinas en relación con el aumento en la longitud corporal de los peces clupeidos. Aunque ninguna de éstas son directamente pertinentes a nuestro estudio, pueden ser apropiadas para otros estudios sobre otras especies de clupeidos. Tales estudios incluyen a Bardán, Navarro, y Rodríguez (1949) sobre *Sardinia pilchardus;* Andreu (1953) sobre *Sardinia pilchardus*; McHugh (1954) sobre *Clupea pallasi*; Montiero (1960) sobre *Sardinella eba;* Scofield (1934) sobre *Sardinops caerulea;* Sako (1938) sobre *Sardinops melanosticta*; Andreu (1955) sobre *Engraulis encrasicolus;* McHugh (1951) sobre *Engraulis mordax mordax;* de Plaza y Boschi (1958) sobre *Engraulis anchoita*; Howard (1954) sobre *Cetengraulis mysticetus*; y Peterson (1956) sobre *Anchovia macrolepidota* y *Anchoa starksi.*

Canal alimentario y alimento

No existen diferencias aparentes en las características externas del canal alimentario entre las cuatro especies del Pacífico. En éstas, todas las partes del tracto digestivo tienen un diámetro similar, con excepción de un engrosamiento muscular, más ancho y bulboso, situado en la porción distal del estómago. En *oglinum,* el diámetro tanto del esófago como del estómago son mayores que en el resto del tracto, y la porción distal del estómago es bulbosa y muscular como en las especies del Pacífico. Parcialmente erróneas son las descripciones breves que Harder (1958 a y b) y Fausto (1961) han hecho sobre el canal alimentario.

El alimento y los hábitos alimentarios serán investigados detalladamente en estudios futuros sobre la biología de estas especies, ya que la apreciable diferencia numérica interespecífica de branquispinas sugiere que existen diferencias en la selección del alimento. Nuestros exámenes del contenido estomacal han sido limitados. En los especímenes que fueron examinados, encontramos muy poco material en el estómago y éste era predominantemente amorfo en apariencia. Los estómagos de especímenes grandes de *bulleri* y *medirastre* frecuentemente contenían un número de crustáceos y pterópodos, mientras que en los especímenes grandes de *libertate* sus estómagos contenían estos mismos organismos pero relativamente en menor número y de menor tamaño. El contenido estomacal de especímenes pequeños (100-120 mm de L. E.) de las tres especies era similar y predominantemente amorfo.

Especies que fueron recolectadas juntas

Todas las tres especies costaneras del Pacífico aparecieron juntas en seis recolecciones; *medirastre* y *bulleri* aparecieron juntas en tres recolecciones; *libertate* y *bulleri* en seis recolecciones; y *libertate* y *medirastre* en 22 recolecciones. En 34 de estas 37 recolecciones de especies múltiples, los tamaños o límites de tamaños de las especies fueron casi iguales o traslapantes. Este hecho no implica necesariamente que las diferentes especies formaban un cardumen en conjunto, ya que los métodos de recolección han podido obtener muestras de cardúmenes diferentes en la misma

área. Sin embargo, en una recolección de *libertate* y *medirastre* de la Bahía Banderas, el 21 de agosto de 1961, ambas especies probablemente integraban el mismo cardumen en la muy pequeña área comprendida por el área circundada por la red.

Especímenes examinados

Nuestros exámenes se basan en el número siguiente de recolecciones y especímenes:

oglinum	63 recolecciones	202 especímenes
berlangai	34 recolecciones	345 especímenes
libertate	150 recolecciones	1914 especímenes
medirastre	63 recolecciones	579 especímenes
bulleri	22 recolecciones	172 especímenes

Los especímenes que fueron examinados se hallan en las colecciones de las instituciones mencionadas en la sección sobre agradecimiento y en el U. S. Bureau of Commercial Fisheries, Biological Laboratory, La Jolla, California.

DISCUSION

Con anterioridad a este estudio, el estado taxonómico de *Opisthonema libertate* y *O. oglinum* era similar a aquel de la mayoría de las especies geminales americanas (o especies pares, o especies cognadas, afines). Se reconocía que pares similares con distribuciones dislocadas, aparecían en el Atlántico Occidental y en el Pacífico Oriental, pero no se ha llevado a cabo la evaluación crítica de estas formas, ya que han sido designadas, un tanto al azar, como especies distintas, como la misma especie, o (menos frecuentemente) como subespecies.

Desde alrededor de 1860 todos los autores han hecho registros de *oglinum* y *libertate* como especies distintas. Usualmente tres caracteres han sido determinados para la separación de las especies: *libertate* tiene pigmentación diferente, cabeza más larga, y mayor número de branquispinas que *oglinum*. Algunos autores han hecho objeciones a una o más de las distinciones sugeridas (como Gilbert y Starks, 1904:40). Ninguno ha informado o evaluado detalladamente estas diferencias. En general, se acepta que el número de branquispinas aumenta con el incremento en la longitud corporal en ciertas especies de clupeidos.

Hemos documentado las diferencias en el complemento de branquispinas y desaprobado la distinción individual de otras diferencias expuestas entre *oglinum* y *libertate* (*sensu stricto*). Es obvio que escritores anteriores quienes declararon que la forma del Pacífico tenía más branquispinas, basaron su diferenciación probablemente en sólo especímenes grandes de *libertate* (*sensu stricto*). Ahora sabemos que hay cuatro formas diferentes en el Pacífico Oriental y que este complejo fué el reconocido previamente como *libertate* (*sensu lato*).

Hay posibles relaciones entre estas cinco formas de *Opisthonema* fuera de la necesariamente subjetiva que hemos usado para designarlas

como cinco especies distintas. Han podido ser designadas como subespecies o como formas polimórficas de una o más especies. Sin embargo, considerando un cierto número de factores asociados, creemos que nuestro punto de vista en cuanto a las relaciones existentes es el más factible.

Tres formas distintas coexisten en una gran distancia latitudinal en aguas costaneras del Pacífico Oriental. Se presume que cada una de éstas consiste de una población continua a través de la totalidad de su campo geográfico. Designarlas como subespecies simpátricas sería excesivamente especulativo sin el conocimiento detallado de las diferencias ecológicas o del microhabitat. Referirnos a ellas como integrantes de una raza trimórfica, no tiene precedente en cuanto a las divergencias conocidas hasta hoy sobre peces del medio ambiente marino, y aunque ésto posiblemente explica las diferencias, no es justificable en el sistema presente de taxonomía morfológica basada en el estudio de especímenes preservados. No es probable que *medirastre,* poseyendo un número intermedio de branquispinas, sea un híbrido, ya que especímenes maduros de todas las cinco formas han sido examinados, y que los especímenes maduros de las tres especies simpátricas han sido hallados en recolecciones completamente segregadas de cada forma como también entremezcladas. Basados en nuestro conocimiento actual, las tres formas simpátricas óptimamente deben considerarse como especies distintas.

La única forma de *Opisthonema* presente en el Atlántico tiene un perfil de branquispinas distinto a aquel de las tres especies costaneras del Pacífico, aunque traslapa los perfiles de estas tres especies a diferentes tamaños. Por su muy prolongado aislamiento de las formas del Pacífico y por la imposibilidad de asignarla definitivamente a una relación subespecífica con qualquiera de éstas, la forma del Atlántico lógicamente se considera como una especie distinta.

La única forma de *Opisthonema* que aparece en las Islas Galápagos se clasifica como una especie distinta. No se considera como subespecie de una de las especies costaneras del Pacífico, aunque el perfil de branquispinas traslapa aquellos de *libertate* y *medirastre.* El mayor traslapo se presenta con *medirastre* del área del Perú a Costa Rica a tamaños de cerca de 120 a 160 mm de L. E., y con *libertate* del área al norte de México a tamaños de aproximadamente 30 a 110 mm de L. E.; también tiene un traslapo apreciable con los especímenes de *oglinum* de las Indias Occidentales a longitudes de cerca de 50 a 80 mm de L. E. Si este traslapo fuese indicativo de una estrecha relación, *i.e.* subespecífica, debería ser máximo con peces de tamaños pequeños menos influido por el medio ambiente (de menos de cerca de 80 a 100 mm de L. E.), y con los especímenes del área (Perú, Ecuador y Panamá), que contribuirían con reclutamientos a las Galápagos en base a las condiciones oceanográficas.

Tal condición combinada no existe. Este raciocinio y cinco factores más, justifican que se reconozca a *berlangai* como una especie distinta. 1) Posee un perfil de branquispinas que es distinto al de todas las otras espe-

cies. 2) Es la única especie de *Opisthonema* que ocurre en las Galápagos, mientras que tres especies aparecen en las costas continentales adyacentes a las Islas. 3) Está aparentemente aislada de las especies costaneras ya que las separa una distancia de más de 500 millas, pues nuestros datos indican que los arenques de hebra del Pacífico no se distribuyen más allá de su habitat costanero. 4) Es evidentemente una población autosustentada (adultos maduros y juveniles muy pequeños han sido examinados). 5) La única forma del Atlántico, *oglinum,* se clasifica como especie distinta en base a un razonamiento similar (por su aislamiento geográfico y perfil de branquispinas característico).

La especulación sobre las relaciones filogenéticas de las cinco especies de *Opisthonema* puede vacilar en un número de direcciones. Si una sola especie existió antes de la separación del Atlántico y del Pacífico por la emergencia del Istmo de Panamá, el progenitor probablemente fué el tipo *bulleri* con un número bajo de branquispinas, o el tipo *oglinum,* más variable y posiblemente más adaptable. *O. medirastre* pudo haber evolucionado de *bulleri* y *libertate* de *medirastre*; *berlangai* desarrollándose de cualquiera de estas últimas.

LITERATURE CITED — BIBLIOGRAFIA CITADA

Alverson, F. G. and B. M. Shimada

1957 A study of the Eastern Pacific fishery for tuna baitfishes, with particular reference to the anchoveta (*Cetengraulis mysticetus*). Inter-Amer. Trop. Tuna Comm., Bull., Vol. 2, No. 2, pp. 21-61 (English), pp. 62-79 (Spanish).

Andreu, Buenaventura

1953 Sobre la relación entre el número de branquispinas y la talla en la sardina (*Sardina pilchardus* Walb.) español.
Bol. Inst. Español Oceanogr., No. 62, pp. 1-28.

1955 The relation between the number of gill rakers and size in the Spanish anchovy from the Atlantic Coast.
Rap. Procés-Verb. Réun. Cons. Perm. Int. l'Explor. Mer, Vol. 137 (3, 9), pp. 29-30.

Baird, S. F.

1855 Fishes observed on the coasts of New Jersey and Long Island during the summer of 1854, by Spencer F. Baird, Assistant Secretary of the Smithsonian Institution.
Smithsonian Inst. Ann. Rept. 1854, pp. 317-358.

Bardán, E., F. de P. Navarro, and O. Rodríguez

1949 Nuevos datos sobre la sardina del Mar de Alboran.
Bol. Inst. Español Oceanogr., No. 17, pp. 1-11.

Barlow, G. W.

1961 Causes and significance of morphological variation in fishes.
Syst. Zool., Vol. 10, No. 3, pp. 105-117.

Barnhart, P. S.

1936 Marine fishes of Southern California.
Univ. Calif. Press, Berkeley, 209 p.

Bean, B. A.

1891 Fishes collected by William P. Seal in Chesapeake Bay, at Cape Charles City, Virginia, September 16 to October 3, 1890.
Proc. U. S. Nat. Mus., Vol. 14, No. 843, pp. 83-94.

Bean, T. H.

1880 Check-list of duplicates of North American fishes distributed by the Smithsonian Institution on behalf of the United States National Museum, 1877-1880.
Proc. U. S. Nat. Mus., Vol. 3, No. 127, pp. 76-116.

Bean, T. H. and H. G. Dresel

1884 A catalogue of fishes received from the public museum of the Institute of Jamaica, with descriptions of *Pristipoma approximans* and *Tylosurus euryops*, two new species.
Proc. U. S. Nat. Mus., Vol. 7, No. 418, pp. 151-170.

Berdegué A., Julio

1956 Peces de importancia comercial en la costa nor-occidental de México.
Sec. Mar., Dir. Gen. Pesca Indust. Conexas, México, 345 p.

1958 Biometric comparison of the anchoveta, *Cetengraulis mysticetus* (Günther), from ten localities of the Eastern Tropical Pacific Ocean.
Inter-Amer. Trop. Tuna Comm., Bull., Vol. 3, No. 1, pp. 1-53 (English), pp. 54-76 (Spanish).

Bertin, Leon

1940 Catalogue des types de poissons du Muséum National d'Histoire Naturelle. 2e partie. Dipneustes, chondrostéens, holostéens, isospondyles.
Bull. Mus. Nat. Hist. Nat., 2 Ser., Vol. 12, No. 6, pp. 244-322.

1941 Mise au point sur quelques espèces de clupéidés.
Bull. Soc. Zool. France, Vol. 66, pp. 18-25.

Bigelow, H. B. and W. C. Schroeder

1953 Fishes of the Gulf of Maine.
U. S. Dept. Int., Fish and Wildlife Serv., Fish Bull. 74, Vol. 53, pp. 1-577.

Bini, G. and E. Tortonese

1955 Missione sperimentale di pesca nel Cile e nel Perú—pesci marini peruviani.
Boll. Pesca Piscicol. e Idrobiol., n.s., Vol. 9, No. 2, pp. 151-185.

Breder, C. M., Jr.
1936 Scientific results of the second oceanographic expedition of the "Pawnee" 1926. Heterosomata to Pediculati from Panama to Lower California.
Bull. Bingham oceangr. Coll., Vol. 2, No. 3, pp. 1-56.
1938 The species of fish in New York Harbor.
Bull. N. Y. Zool. Soc., Vol. 41, No. 1, pp. 23-29.

Broussonet, P. M. A.
1782 Ichthyologia sistens piscium descriptiones et icones.
Petr. Elmsley, Londini, Vol. 1, 41 p.

Butler, J. A.
1961 Development of a thread-herring fishery in the Gulf of Mexico.
Comm. Fish. Rev., Vol. 23, No. 9, pp. 12-17.

Campos, A. A.
1942 Contribuicão ao estudo dos clupeoides das aguas brasileiras.
Arq. Zool. Est. São Paulo, Vol. 3, No. 26, pp. 185-218.

Chapman, W. McL.
1944 The comparative osteology of the herring-like fishes (Clupeidae) of California.
Calif. Fish and Game, Vol. 30, No. 1, pp. 6-21.

Clothier, C. R.
1950 A key to some Southern California fishes based on vertebral characters.
Calif. Div. Fish and Game, Fish Bull., No. 79, 83 p.

Cuvier, G. and A. Valenciennes
1847 Histoire naturelle des poissons.
V. Levrault, Paris, Vol. 20, pp. xviii + 472.

David, L. R.
1943 Miocene fishes of southern California.
Geol. Soc. Amer., Spec. Pap. 43, 193 p.

DeKay, J. E.
1842 Zoology of New York, or the New York fauna . . . Part IV. Fishes. (Vol. 1 in Natural History of New York by the Geological Survey).
W. and A. White and J. Visscher, Albany, N. Y., 415 p. (sep. vol. pls.).

Evermann, B. W. and O. P. Jenkins
1891 Report upon a collection of fishes made at Guaymas, Sonora, Mexico, with descriptions of new species.
Proc. U. S. Nat. Mus., Vol. 14, No. 846, pp. 121-165.

Evermann, B. W. and M. C. Marsh

1902 The fishes of Porto Rico.
U. S. Fish Comm., Bull., Vol. 20, No. 1, pp. 49-350.

Fausto, José, Filho

1961 Sobre o tubo digestivo em *Opisthonema* Gill, 1861.
Bol. Est. Biol. Mar., Univ. Ceará, No. 2, pp. 1-3.

Fitch, J. E.

1948 Some new and unusual fishes from southern California.
Calif. Fish and Game, Vol. 34, No. 3, pp. 133-135.

Fowler, H. W.

1906 The fishes of New Jersey.
N. J. State Mus. Ann. Rep. 1905, No. 2, pp. 35-477.

1911a The fishes of Delaware.
Proc. Acad. Nat. Sci. Philadelphia, pp. 1-16.

1911b Notes on clupeoid fishes.
Ibid., pp. 204-221.

1932 The fishes obtained by the Pinchot South Seas Expedition of 1929, with descriptions of one new genus and three new species.
Proc. U. S. Nat. Mus., Vol. 80, Art. 6, No. 2906, pp. 1-16.

1938 The fishes of the George Vanderbilt South Pacific Expedition.
Monogr. Acad. Nat. Sci. Philadelphia, Vol. 2, 349 p.

1941 A list of the fishes known from the coast of Brazil.
Arq. Zool. Est. São Paulo, Vol. 3, No. 6, pp. 115-184.

1944 Results of the fifth George Vanderbilt Expedition (1941), (Bahamas, Caribbean Sea, Panama, Galapagos Archipelago and Mexican Pacific Islands). The fishes.
Monogr. Acad. Nat. Sci. Philadelphia, No. 6, pp. 57-529.

1945 A study of the fishes of the southern Piedmont and coastal plain.
Ibid., No. 7, 408 p.

Gilbert, C. H.

1891 Scientific results of explorations by the U. S. Fish Commission steamer Albatross. No. XIX. A supplementary list of fishes collected at the Galapagos Islands and Panama, with descriptions of one new genus and three new species.
Proc. U. S. Nat. Mus., Vol. 13, No. 840, pp. 449-455.

Gilbert, C. H. and E. C. Starks

1904 The fishes of Panama Bay.
Mem. Calif. Acad. Sci., Vol. 4, No. 32, 304 p.

Gill, T. N.

1861 Synopsis of the subfamily Clupeinae, with descriptions of new genera.
Proc. Acad. Nat. Sci. Philadelphia, pp. 33-38.

1873 Catalogue of the fishes of the East coast of North America. U. S. Comm. Fish and Fish. Part I. Rep. Sea Fish. South coast New England 1871 and 1872, Appendix, pp. 779-882. Sep. Smithsonian Misc. Coll. No. 283, 50 p.

Goode, G. B.

1877 A preliminary catalogue of the reptiles, fishes and leptocardians of the Bermudas, with descriptions of four species of fishes believed to be new.
Amer. Jour. Sci. and Arts, Vol. 14, pp. 289-298.

1879 A preliminary catalogue of the fishes of the St. John's River and the East coast of Florida, with descriptions of a new genus and three new species.
Proc. U. S. Nat. Mus., Vol. 2, No. 73, pp. 108-121.

Goode, G. B. and T. H. Bean

1879 Catalogue of a collection of fishes sent from Pensacola, Florida, and vicinity, by Mr. Silas Stearns, with descriptions of six new species.
Proc. U. S. Nat. Mus., Vol. 2, No. 74, pp. 121-156.

1882 A list of the species of fishes recorded as occurring in the Gulf of Mexico.
Ibid., Vol. 5, No. 281, pp. 234-240.

1885 On the American fishes in the Linnaean collection.
Ibid., Vol. 8, No. 510, pp. 193-208.

Gosse, P. H.

1851 A naturalist's sojourn in Jamaica.
Longmans, Brown, Green and Longmans, London, xxiv + 508 p.

Günther, Albert

1866 The fishes of the states of Central America, founded upon specimens collected in the fresh and marine waters of various parts of that country by Messrs. Salvin and Godman and Capt. J. M. Dow. (Informal title).
Proc. Zool. Soc. London, No. 39, pp. 600-604.

1868a An account of the fishes of the states of Central America, based on collections made by Capt. J. M. Dow, F. Godman, Esq., and O. Salvin, Esq.
Trans. Zool. Soc. London, Vol. 6, Pt. 7, No. 14, pp. 377-494.

1958b Catalogue of the Physostomi . . . in the collection of the British Museum.
Taylor and Francis, London, 512 p.

Harder, Wilhelm

1958a The intestine as a diagnostic character in identifying certain clupeoids (Engraulididae, Clupeidae, Dussumieriidae) and as a morphometric character for comparing anchoveta (*Cetengraulis mysticetus*) populations.
Inter-Amer. Trop. Tuna Comm., Bull., Vol. 2, No. 8, pp. 365-380 (English), pp. 381-388 (Spanish).

1958b Zur Anatomie des Darmtraktes einiger Familien der Clupeoidea: Clupeidae, Dorosomatidae, Dussumieriidae und Engraulididae (Clupeiformes, Pisces.).
Sond. Kurze Mitt. Inst. Fisch. Univ. Hamburg, No. 8, pp. 11-61.

Herre, A. W.

1936 Fishes of the Crane Pacific expedition.
Field Mus. Nat. Hist., Zool. Ser., Vol. 21, No. 353, 472 p.

Hildebrand, S. F.

1925 Fishes of the republic of El Salvador, Central America.
U. S. Bur. Fish., Bull., Vol. 41, No. 985, pp. 237-287.

1946 A descriptive catalog of the shore fishes of Peru.
Bull. U. S. Nat. Mus., No. 189, 530 p.

Hildebrand, S. F. and W. C. Schroeder

1928 Fishes of Chesapeake Bay.
U. S. Bur. Fish., Bull., Vol. 43, No. 1, 366 p. (1927).

Howard, G. V.

1954 A study of populations of the anchoveta, *Cetengraulis mysticetus*, based on meristic characters.
Inter-Amer. Trop. Tuna Comm., Bull., Vol. 1, No. 1, pp. 1-24.

Jordan, D. S.

1885 A list of the fishes known from the Pacific coast of tropical America, from the Tropic of Cancer to Panama.
Proc. U. S. Nat. Mus., Vol. 8, No. 526, pp. 361-394.

1886a Notes on fishes collected at Beaufort, North Carolina, with a revised list of the species known from that locality.
Ibid., Vol. 9, No. 550, pp. 25-30.

1886b List of fishes collected at Havana, Cuba, in December, 1883, with notes and descriptions.
Ibid., Vol. 9, No. 551, pp. 31-55.

1887a A preliminary list of the fishes of the West Indies.
Ibid., Vol. 9, No. 595, pp. 554-608.

1887b A catalogue of the fishes known to inhabit the waters of North America, North of the Tropic of Cancer, with notes on the species discovered in 1883 and 1884.
U. S. Comm. Fish & Fish., Pt. 13, Rep. Comm. 1885, pp. 789-973.

1890 Scientific results of explorations by the U. S. Fish Commission Steamer Albatross. No. IX. Catalogue of fishes collected at Port Castries, St. Lucia, by the steamer Albatross, November, 1888.
Proc. U. S. Nat. Mus., Vol. 12, No. 789, pp. 645-652.

1891 Scientific results of explorations by the U. S. Fish Commission steamer Albatross. No. XVIII. List of fishes obtained in the harbor of Bahia, Brazil, and in adjacent waters.
Ibid., Vol. 13, No. 829, pp. 313-336.

1919 The genera of fishes. Part III . . .
Leland Stanford Junior Univ., Pub. Univ. Ser., pp. 283-410 + i-xv.

Jordan, D. S. and B. W. Evermann

1896 The fishes of North and Middle America.
U. S. Nat. Mus., Bull., No. 47(1), 1240 p.

Jordan, D. S., B. W. Evermann, and H. W. Clark

1930 Check list of the fishes and fishlike vertebrates of North and Middle America.
U. S. Comm. Fish. Rep. 1928, Appendix 10, 670 p.

Jordan, D. S. and C. H. Gilbert

1879 Notes on the fishes of Beaufort Harbor, North Carolina.
Proc. U. S. Nat. Mus., Vol. 1, No. 55, pp. 365-388.

1882a Notes on fishes observed about Pensacola, Florida, and Galveston, Texas, with descriptions of new species.
Ibid., Vol. 5, No. 282, pp. 241-307.

1882b Synopsis of the fishes of North America.
U. S. Nat. Mus., Bull., No. 16, lv + 1018 p.

1883a On certain neglected generic names of La Cépède.
Proc. U. S. Nat. Mus., Vol. 5, No. 324, pp. 570-576.

1883b List of fishes now in the museum of Yale College, collected by Prof. Frank H. Bradley, at Panama, with descriptions of three new species.
Proc. U. S. Nat. Mus., Vol. 5, No. 329, pp. 620-632.

Jordan, D. S., E. C. Starks, G. B. Culver, and T. M. Williams

1895 The fishes of Sinaloa.
Proc. Calif. Acad. Sci., 2 Ser., Vol. 5, pp. 377-514.

LeSueur, C. A.

1818 Descriptions of several new species of North American fishes.
Jour. Acad. Nat. Sci., Philadelphia, Vol. 1, No. 1, pp. 359-368.

Linnaeus, Carolus

1758 Systema Naturae.
L. Salvii, Holmiae, Ed. 10, Vol. 1, 823 p.

1766 Systema Naturae.
Ibid., Ed. 12, Vol. 1, 531 pp.

MacCoy, C. V.

1931 Fishes. (Museum notes).
Bull. Boston Soc. Nat. Hist., No. 61, p. 21.

McHugh, J. L.

1950 Variations and populations in the clupeoid fishes of the North Pacific.
Unpub. thesis, Univ. Calif., Los Angeles, 116 p.

1951 Meristic variations and populations of northern anchovy (*Engraulis mordax mordax*).
Bull. Scripps Inst. Oceanogr., Univ. Calif., Vol. 6, No. 3, pp. 123-160.

1954 Geographic variation in the Pacific herring.
Copeia, No. 2, pp. 139-151.

McHugh, J. L. and J. E. Fitch

1951 An annotated list of the clupeoid fishes of the Pacific coast, from Alaska to Cape San Lucas, Baja California.
Calif. Fish and Game, Vol. 37, No. 4, pp. 491-495.

Meek, S. E. and S. F. Hildebrand

1923 The marine fishes of Panama. Part I.
Field Mus. Nat. Hist., Zool. Ser., Vol. 15, No. 215, 330 p.

Monteiro, Rui

1960 Contribuicões para o estudo da biologia dos "Clupeidae" de Angola. 2.—Observacões métricas e marísticas em *Sardinella eba* C. & V.
Notas Mimeogr., Centro Biolo. Piscat., Lisbon, No. 15, pp. 1-13.

Morrow, J. E.

1957 Shore and pelagic fishes from Peru, with new records and the description of a new species of *Sphoeroides*.
Bull. Bingham oceanogr. Coll., Vol. 16, Art. 2, No. 1, pp. 5-55.

Nichols, J. T.

1912 Notes on Cuban fishes.
Bull. Amer. Mus. Nat. Hist., Vol. 31, No. 18, pp. 179-194.

1921 A list of Turk Island fishes, with a description of a new flatfish. *Ibid.*, Vol. 44, No. 3, pp. 21-24.

Nichols, J. T. and R. C. Murphy

1944 A collection of fishes from the Panama Bight, Pacific Ocean.
Bull. Amer. Mus. Nat. Hist., Vol. 83, No. 4, pp. 219-260.

Osburn, R. C. and J. T. Nichols

1916 Shore fishes collected by the 'Albatross' Expedition in Lower California with descriptions of new species.
Bull. Amer. Mus. Nat. Hist., Vol. 35, No. 16, pp. 139-181.

Peterson, C. L.

1956 Observations on the taxonomy, biology, and ecology of the engraulid and clupeid fishes in the Gulf of Nicoya, Costa Rica. Inter-Amer. Trop. Tuna Comm., Bull., Vol. 1, No. 5, pp. 137-212 (English), pp. 213-280 (Spanish).

Plaza, M. L. F. de and E. E. Boschi

1958 Estudio biologico pesquero de la anchoita (*Engraulis anchoita*) del Mar del Plata. I. Analisis de los caracteres meristicos. Pub. Depart. Invest. Pesq., Sec. Agric. Ganadería Argentina, No. 7, pp. 1-49.

Poey, Felipe

1881 Peces. *In* Gundlach, J. Apuntes para la fauna puerto-riqueña. Anal. Soc. Español Hist. Nat., Madrid, Vol. 10, pp. 317-350 (*not seen*).

Radovich, John

1960 Redistribution of fishes in the eastern North Pacific Ocean in 1957 and 1958. Calif. Coop. Oceanic. Fish. Invest., Repts., Vol. 7, pp. 163-171.

1961 Relationships of some marine organisms of the northeast Pacific to water temperatures particularly during 1957 through 1959. Calif. Div. Fish and Game, Fish Bull., No. 112, 62 p.

Regan, C. T.

1904 Descriptions of new or little-known fishes from Mexico and British Honduras. Ann. Mag. Nat. Hist., Ser. 7, Vol. 8, pp. 255-259.

1917a A revision of the clupeoid fishes of the genera *Pomolobus, Brevoortia* and *Dorosoma,* and their allies. *Ibid.,* Ser. 8, Vol. 19, pp. 297-316.

1917b A revision of the clupeid fishes of the genera *Sardinella, Harengula,* &c. *Ibid.,* Vol. 19, pp. 377-395.

Sako, Noboru

1938 On the gill-rakers of *Sardinia melanosticta* (Temminck & Schlegel). Bull. Jap. Soc. Sci. Fish., Vol. 7, pp. 237-238.

Schaefer, M. B.

1954 Report on the investigations of the Inter-American Tropical Tuna Commission for the year 1953. Inter-Amer. Trop. Tuna Comm., Ann. Rep. 1953, pp. 18-50 (English), pp. 51-87 (Spanish).

1961 Report on the investigations of the Inter-American Tropical Tuna Commission for the year 1960.
Ibid., 1960, pp. 40-107 (English), pp. 108-183 (Spanish).

Scofield, E. C.

1934 Early life history of the California sardine (*Sardina caerulea*), with special reference to the distribution of the eggs and larvae. Calif. Div. Fish and Game, Fish Bull., No. 41, 48 p.

Slevin, J. R.

1959 The Galápagos Islands, a history of their exploration.
Occ. Pap. Calif. Acad. Sci., No. 25, 150 p.

Snodgrass, R. E. and E. Heller

1905 Papers from the Hopkins-Stanford Galapagos Expedition. XVIII. Shore fishes of the Revillagigedo, Clipperton, Cocos and Galapagos Islands.
Proc. Wash. Acad. Sci., Vol. 6, pp. 333-427.

Springer, Stewart

1957 Some observations on the behavior of schools of fishes in the Gulf of Mexico and adjacent waters.
Ecology, Vol. 38, No. 1, pp. 166-171.

Storey, Margaret

1938 West Indian clupeid fishes of the genus *Harengula* with notes on *H. thrissina* from the Pacific coast.
Stanford Ichthyol. Bull., Vol. 1, No. 1, pp. 3-56.

Tabb, D. C. and R. B. Manning

1961 A checklist of the flora and fauna of northern Florida Bay . . .
Bull. Mar. Sci. Gulf and Carib., Vol. 11, No. 4, pp. 552-649.

Villagomez, G. O.

1948 Notas sobre algunos peces Ecuatorianos.
Bol. Inform. Cient. Nac., Vol. 11, No. 11-12, pp. 51-56.

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Passage of Salmon Fingerlings Through Small Tunnels

INTRODUCTION

A knowledge of the physical factors which affect the behavior of fish when approaching and entering small tunnels is of importance in operating electronic fish-counting tunnels. Fish passing into and through such tunnels unbalance conductivity bridges which actuate an electric tally. Maximum efficiency of these tunnels is afforded by a rapid attraction and passage of fish as they enter the bypass system. The accuracy of the counting device is greatly decreased if large numbers of fish collect upstream and then pass through the tunnels *en masse*. Conditions providing for a minimum of delay in the bypass area will tend to reduce such concentrations.

A series of tests was conducted to determine the optimum combination of water velocity and light condition that will most effectively facilitate downstream passage of salmon fingerlings through small tunnels.

METHODS AND EQUIPMENT

All laboratory experiments were conducted in an open wooden trough 8 feet long by 24 inches wide by 24 inches deep. Water in the trough was recirculated by a 500-gallon-per-minute pump. The temperatures ranged from 47 to 49° F.

The range of water velocities tested (1.5 to 3.5 feet per second) was selected after study of data previously collected at a field installation. Control of velocities was achieved by regulation of the pump and head differential. Water velocities were measured at the mouth of the tunnel prior to testing.

Four light conditions were used: (1) Light on downstream side of tunnel weir; (2) light on upstream side of tunnel weir; (3) light on both sides of tunnel weir; and (4) complete darkness (all lights out). Under conditions 1 and 2, a small amount of light penetrated through the tunnel into the darkened area beyond the weir. The lights were placed 4 inches above the water surface and 4 inches from each side of the tunnel weir. Light level was held constant under each condition and regulated with a variable voltage transformer.

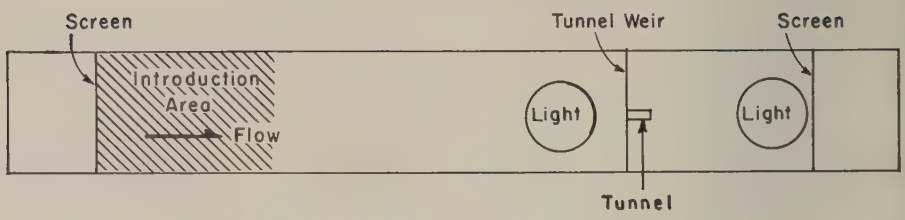

FIGURE 1.—Plan view of test channel showing location of tunnel and lights. The water was recirculated through the system by pumping from a large reservoir.

Fifty volts were supplied to standard 40-watt bulbs. The test area was completely isolated from all extraneous light sources.

The tunnel was molded from translucent plastic material and measured 2$\frac{7}{16}$ inches in inside diameter and 4 inches in length. Initial tunnel size was selected arbitrarily, considering only the size of the fish to be tested.

Each group of fish was introduced into the trough at a point upstream from the tunnel (Figure 1). The duration of each complete test was 10 minutes. At the end of the test period, the number of fish that had passed downstream through the tunnel was recorded. This figure was converted to percentage of the total number introduced.

Salmon fingerlings used for these tests were yearling sockeye (*Oncorhynchus nerka*) ranging in size from 70 to 110 millimeters. The fish were raised at the National Fish Hatchery, Leavenworth, Washington. Before testing the fish were acclimated to the test light level for a period of 10 minutes. The experiment consisted of four "blocks" of tests, each block consisting of four tests at a constant light condition with only the water velocity being varied. A new group of fish was used in each test.

TABLE 1.—*Passage of sockeye salmon fingerlings through a counting tunnel under various light and water velocity conditions*[1]

Velocity at mouth of tunnel (Feet per second)	Percentage passing downstream through tunnel within 10 minutes			
	Downstream light only	Both lights off	Both lights on	Upstream light only
3.5	88	64	24	24
3.0	84	52	0	0
2.5	56	36	4	4
1.5	48	28	0	0

[1] Twenty-five fish were used for each of the 16 tests, totaling 400.

RESULTS

Results of these tunnel tests indicated that the higher velocities 3.0 to 3.5 f.p.s., in combination with downstream light only, induced the highest percentage of downstream passage (Table 1).

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Scales and Earstones Reveal Age of Atlantic Herring

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Fluctuations in catches of commercial marine fish such as herring are of great practical importance. Determination of the number of fish of different ages in a population can help to assess the fluctuations that often occur, and may provide some advance information about the success of the fishery. Ageing data per se has limited value, but when combined with other information, helps the fishery scientist determine (1) the amount of growth in a given period of time, (2) the length of time before a fish reaches a marketable size, and (3) what the fluctuations in abundance of particular age groups have been from year to year.

One of the ageing methods used in the United States and Canada for herring is the length-frequency distribution. This method is based on the assumption that after each year's growth, the length of the fish will be within a certain size range. Another method used for herring ageing is counting rings on scales and earstones. The earstones are granules of calcium carbonate which are attached to sensitive cells in the fish's inner ear and function as an organ of balance. The scale and earstone method is based on the premise that concentric rings are formed annually on these parts. The number of rings can be used to determine the age of a fish in the same manner as the rings in a cross section of a tree trunk can be used to establish the age of a tree (figure 1).

Herring are difficult to age. In many cases fish spawned at different locations and at different times of the year are found living together, and attempts to age these samples by the length-frequency method are often impossible. Age analysis by scales and earstones is by no means foolproof, but appears to be the best method at our disposal.

With herring, the rings on scales and earstones are formed principally in the cold months of the year when activity is at a minimum and growth decreases. The interval between successive winter rings has been shown to represent one year's growth. Careful study over a long period of time has enabled biologists to recognize other types of marks such as spawning check rings and the false rings formed during periods of sudden or prolonged changes in the fish's environment.

The age composition of the parent population enables biologists to understand more clearly the future overall picture of the availability and abundance of the immature herring (used as sardines). At the Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine, scales and earstones have been examined from adult herring from Gulf of Maine and Bay of Fundy waters. Ages of fish derived from studies of scales were checked against those determined from earstones in the same fish (figures 2 and 3). To date, samples of both scales and earstones from more than 1,000 fish have been examined. Preliminary analyses of our data suggested that the adult herring population was made up primarily of 4- and 5-year-old fish. These fish ranged in length from approximately 8 to 13 inches.

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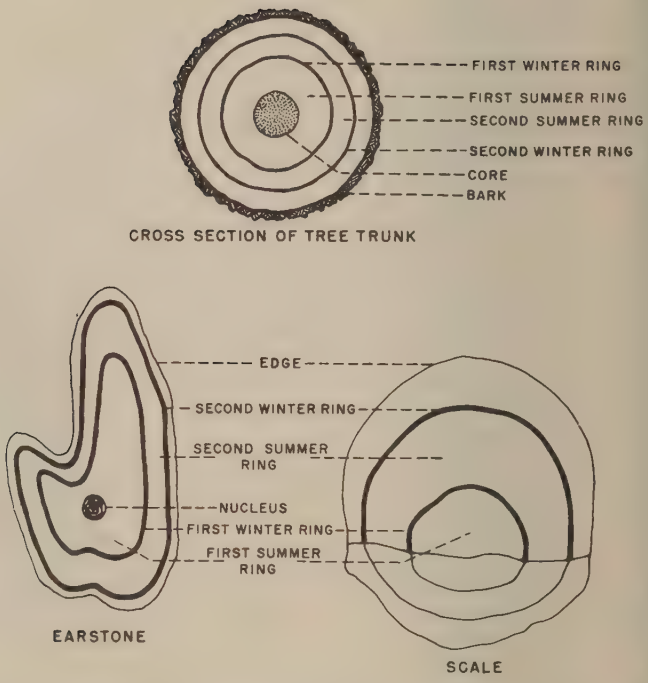

Figure 1. An idealized comparison of growth between annual rings of scales, earstones, and tree (cross section of trunk). Annual growth rings include both winter and summer rings.

Figure 2. Earstones of herring with four winter rings as seen under the microscope.

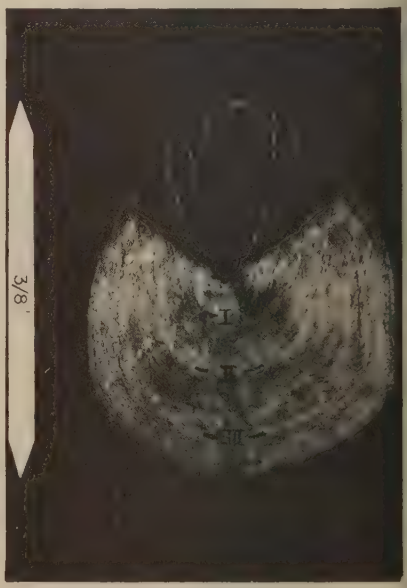

Figure 3. Scale of herring with four winter rings as seen under the microscope.

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Will Tuna Research Change Direction?

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Abstract

The World Scientific Meeting on the Biology of the Tunas and Related Species was held in Ja Jolla, California, during July 2-14, 1962. Convened by the Food and Agriculture Organization of the United Nations, the objectives of the meeting were to appraise the present knowledge of the tunas and to recommend future lines of endeavor.

In general session and discussion groups, the participants considered the development and current commercial exploitation of the tuna fisheries and the identity, distribution, behavior and potential yields of the stocks. It was revealed that through tagging and serological studies, the distribution of some stocks was becoming apparent and that responses to subtle environmental differences may separate these stocks.

Results of research on behavior of tuna in captivity and at sea suggested the need for studies of the physiology of these fish.

The work in the eastern Pacific by the Inter American Tropical Tuna Commission on the population dynamics emphasized the need for adequate catch statistics for the expanding tuna fisheries of the world and the Meeting recognized the need for economic studies in order to achieve a more adequate understanding of these fisheries.

THE WORLD SCIENTIFIC MEETING on the Biology of the Tunas and Related Species, held at La Jolla, California, July 2-14, 1962, by the Food and Agriculture Organization of the United Nations, provided a resume of the current position of research on the tunas. The position thus developed could be compared to that of a healthy vigorous baby; a good start has been made, but the greater part of its growth and development lie ahead.

Fisheries research is a young science and research on tuna biology, as a continuing effort, is a fairly recent addition to that science with a history of 40 or possibly 50 years. However, only in the period since the end of World War II has tuna research enjoyed an effective level of support, a level that the results of the world meeting clearly demonstrates is rapidly increasing.

In the long view, research on the tunas and related species seeks an understanding of these fishes as a harvestable portion of the living organisms of the sea, resources that transforms the energy of the sun and substances in the water into usable protein. For this understanding to be complete, we must know the entire mechanism of the pelagic ecosystem and beyond that, the interactions of that ecosystem with others and with the sun and atmosphere. Although the

desired degrees of understanding will never be achieved, each additional increment of knowledge will prove valuable to man in his efforts to more wisely and efficiently harvest the marine food resources.

In addition, as a complement to the knowledge of the fish and their environment, we need knowledge of the most efficient techniques for harvesting these fish. This implies an understanding of the interactions of the fishermen, their vessels, and the gear with the pelagic ecosystem and, in particular, with the tunas. Beyond these relationships lie those of processing, distribution, and sale of the catch.

We cannot ask that our research efforts be complete, but rather that they be planned and carried out in a manner to develop our understanding of the tunas as a harvestable portion of the living resources of the sea, and further to contribute to the efficiency of that harvest. The meeting at La Jolla provided an opportunity to evaluate the level of our knowledge and where we proposed to go.

The meeting was organized into eight sections; the Chairman for each pre pared a review and led the discussions. The sections were: (1) Species identification and distribution subdivided into (A) Adults and (B) Larvae and eggs, (2) Population identification, (3) Size and composition of stocks, (4) Availability (accessibility and vulnerability), (5) Physiology and behavior, (6) Fishing methods, (7) Statistics of catch and effort, and (8) Future lines of tuna research.

The last item was a summary of the possible future research in each of the preceeding sections. The discussion today will be concerned with this summary, with future lines of tuna research organized on the same subject divisions, but not necessarily in the same order as the organization sections for the meeting.

Problems of the identification of the species of adult tunas were found to be largely solved. There were a few questions remaining concerning some genera such as *Sarda, Scomberomorus,* and *Scomber.* The identity of larval tunas was being resolved except for the albacore and for some of the bonitos; however, both additional growth stages and independent lines of evidence for the identity of the larvae of species other than albacore and bonitos were considered desirable.

The identification of tuna populations is off to a good start. The important tools have been studies of the differences in body form and the results of tagging. A recent method, the study of differences in blood group systems by immunelogical techniques, is showing considerable promise. Knowledge concerning independant populations, their magnitude, rates of replenishment, and boundaries, is required since the unit with which a fisheries biologist must work is the interbreeding, independent unit of population.

A large part of the information concerning tunas is available as a result of operation of commercial fisheries. A fleet of fishing vessels, by the magnitude of its activities, is, in scope, a sampling apparatus for beyond that which the research worker can hope to independently provide. Data resulting from proper documentation of the operations of tuna fleets is essential to studies concerned with the responses of fish populations to oceanographic changes, with the consequences of harvests by fishermen on the magnitude of the populations, and with life histories and growth.

Tuna fisheries in the oceans of the world are expanding, both in amount of

harvest and areal extent of fishing grounds. This expansion is at such a rapid rate that adequate documentation is badly lagging.

The history of the yellowfin tuna fishery of the eastern Pacific has provided evidence that the maximum sustainable yields for a tuna fishery can be exceeded. The catch records for this fishery are of high quality which, in general, is an unusual situation for tuna fisheries. There is a pressing need to provide some machinery, presumably of international character, to document those tuna resources fished jointly by a number of nations, such as for example, in the tropical Atlantic where no really adequate system of catch records exist. The point of maximum sustainable yield may be grossly exceeded without being plainly demonstratable as a consequence of fishing. This need will grow as the world tuna fisheries grow. The annual landings are currently about 1,000,000 short tons and are increasing at a rate that will possibly double this value within ten years.

The possibility of the continued rapid expansion of the world harvest of tunas is a major factor in the determination of the major research problems and associated priorities. As suggested above, an essential tool involves assembling data resulting from adequate documentation of the catch and of the fishing effort. These data provide a means for understanding the consequence of the existing fisheries on the stocks and will also serve to measure the effects of environmental changes. The harvest of some species of tuna may be considerably increased with development of new and more efficient methods of capture. Effective harvest of skipjack tuna, a major species that is seriously underfished, requires the development of new gear, or perhaps modifications of present gear, if skipjack fisheries are to be effectively expanded into the central and western parts of tropical oceans. Also, gear that will efficiently take some species of tuna at those ages and sizes where the population mass is greatest should be developed.

Oceanographic mechanisms that may increase the local availability of the fish need to be understood sufficiently well so that the time and place of their occurrence can be predicted. This will involve the requisite oceanographic studies and those of fish behavior, the latter both in response to the environment and to the operation of fishing gear.

Implicit in these research goals are many areas of scientific endeavor, some of which although essential, may appear to possess little immediate application. The organization and coordination of research programs, in order to provide effective progress and to prevent lost effort, are matters that require consideration on both national and international levels. More than any other fishery resource, the tunas are the property of all nations; their exclusive fishery the privilege of none.

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Developing Tropical Atlantic Fisheries Through International Research

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Abstract

The Intergovernmental Oceanographic Commission of UNESCO, at the meeting of the Second Session in Paris, September, 1962, adopted an international program of physical, chemical, and biological research for the tropical Atlantic. Mr. Vernon E. Brock, Bureau of Commercial Fisheries, was appointed as International Coordinator. Seven nations have committed a total of 15 research vessels to this program. Two synoptic surveys, one each during midwinter and midsummer, are scheduled for 1963. The results of these surveys, to be published both as data reports and atlases, will be used to design a program of research concerned with the character and magnitude of the pelagic fishery resources of the tropical Atlantic.

THE INTERNATIONAL COOPERATIVE INVESTIGATIONS of the Tropical Atlantic will involve a minimum of fifteen oceanographic vessels of seven nations together with research workers from at least three additional nations. Results of these investigations, scheduled for mid-winter and midsummer, 1963, will provide a synoptic picture of the tropical Atlantic from the west coast of Africa to the east coast of South America.

The EQUALANT I plan involves three phases. First, a 15-day synoptic set of physical, chemical and biological observations along tracks across the equator. Next, during a second 15-day period, studies of the equatorial circulation, through direct current measurements, will be made from some of the participating vessels, while others will pursue a variety of special studies. Finally, a repeat of the initial 15-day synoptic survey is scheduled. In addition to the programs common to all vessels and to the special studies mentioned for the middle 15-day period, a variety of special studies will be undertaken aboard many of the vessels during the 15-day synoptic survey periods. Work by Bureau and participating scientists aboard the GERONIMO, for example, includes sampling forage and benthic organisms (Bureau of Commercial Fisheries, U.S. National Museum, and University of Hamburg), studies in primary productivity (Yale University), and upper air meteorological observations (U. S. Weather Bureau).

In order to obtain the maximum practicable degree of uniformity for certain observations, the Bureau of Commercial Fisheries Biological Laboratory will supply C^{14} kits and instructions, arrange for counting of the planchettes at one laboratory, provide one-meter plankton nets, and arrange for determining volume of the samples.

The International Cooperative Investigations of the Tropical Atlantic represent the largest and most concentrated attempt to understand the Tropical Atlantic Ocean to date. The International Indian Ocean Expedition is much larger, and less tightly integrated. Although there have been larger efforts in the Pacific, the program in the Atlantic has at least one unique characteristic. It is the first international cooperative venture wholly within the framework of the recently formed Intergovernmental Oceanographic Commission; the Indian Ocean expedition began before the Commission was established. It will provide a testing ground for the coordinating mechanisms of that Commission.

The investigations are a concrete expression of the growing interest in the oceanography and the living resources of the tropical Atlantic Ocean. As far as the living resources are concerned, two meetings held in Africa in 1960 served as a focus for this interest. The meeting of specialists on oceanography and sea fisheries held in Monrovia in December, 1960, considered problems relating to the demersal fisheries of the African shelf; the Symposium on Thunnidae in Dakar in the same month was concerned with the tuna fisheries of the eastern tropical Atlantic. The serious shortage of dietary protein for millions of people in West Africa, and the possibilities of utilizing the fisheries of the eastern Atlantic to alleviate this shortage, were factors in stimulating interest in these fisheries.

Early in 1961 proposals for two programs were developed, one concerned with the demersal fisheries and the other with the pelagic. The demersal fishery program was initially proposed by Dr. Postel, the Scientific Coordinator for CCTA (Commission for Technical Cooperation in Africa South of the Sahara). The proposal for investigations concerned with the pelagic fisheries came from the Director of the Bureau of Commercial Fisheries. The request to AID (Agency for International Development) for support of the demersal investigations of CCTA, brought this program to the attention of fisheries scientists in the Bureau of Commercial Fisheries and resulted in the proposal to strengthen both the demersal and pelagic fisheries investigations by a coordinated attack.

In August, 1961, CCTA assembled a group of advisers in Lagos to plan the investigations of demersal fisheries. At this meeting, the schedule involved two, four-month periods of field work, one beginning in January and the other in July. The field work would consist of a series of trawl hauls made along five transects paralleling the coast, each transect at a different depth from shallow to deep water (15 to 600 meters). These hauls would be made by two research trawlers working station lines positioned 30 to 40 miles apart within an area between Cape Roxo (11°N) and Mossamedes (15°S).

The implementation of the CCTA trawling campaign was initiated in September, 1962, with the selection of the Scientific Director. He immediately began negotiations for suitable vessels and recruitment of a staff.

The implementation of the Bureau of Commercial Fisheries proposal for investigations of the pelagic fisheries of the eastern tropical Atlantic began during the fall of 1961 with the recruitment of the nucleus of a staff for this purpose at the Bureau's Biological Laboratory in Washington, D. C.

Some preliminary examination of available data for the eastern tropical tlantic was made and the general plan of the investigations formulated. On ebruary 26, 1962, the Director of the Bureau of Commercial Fisheries Biolo- cal Laboratory, Washington, D. C., arranged for a meeting with oceanogra- hers in the eastern United States to explore the degree of interest in coopera- ve work in the tropical Atlantic. A high degree of interest in a cooperative nvestigation of this region was evident. Participants in the meeting proposed hat the investigations be submitted to the IOC for consideration as an inter- ational effort.

The results of the February meeting were presented to the Bureau of the ntergovernmental Oceanographic Commission in April. The Department of tate subsequently issued invitations to interested member countries and activi- ies of the IOC, and, under the auspices of IOC, an International Working Group assembled in Washington, D.C., on June 20-22, 1962. The details of a rogram for the proposed investigations of the tropical Atlantic were developed y the participants in this meeting. This program was subsequently adopted t the September meeting of the IOC in Paris, and an International Coordinator elected.

I have given briefly the character and history of the International Cooperative nvestigations of the Tropical Atlantic. It is apparent that these investigations vill be largely concerned with a synoptic description of this region, primarily vith the physical, chemical, and marine biological aspects. The character of he investigations reflect the common areas of interest of the investigators and, y being a joint effort, are much more extensive than would otherwise be ossible.

However, their completion will provide a basis for further studies which, to a degree, will have less of the character of a common or joint operation. This s so because these future studies will be more advanced and be directed owards goals of the special interests of the investigators—such as those related o our interest in the tuna fisheries. The remaining areas of common interests vill be cooperatively investigated to the degree that such cooperation is ad- vantageous.

The fisheries investigations, following EQUALANT I and II, will be con- cerned with the character of and the relations among the variations in abun- dance of pelagic fish stocks, in both space and time, and with the physical and biological environmental parameters that may influence these stocks. The synoptic oceanographic investigations completed during EQUALANT I and I will serve as guides in determining the regions where detailed studies of the pelagic fishes might be most profitably pursued. Further investigations of physical and biological oceanography of the region will probably involve both he establishment of monitoring stations, scheduling of cruises for periodic bservations, and will include intensive studies for relatively restricted areas. In addition to these environmentally oriented investigations, work concerned vith the accessibility of pelagic fishes to such gear as the purse seine is planned.

I have not attempted to give all the details of the work proposed in the tropical Atlantic since these are readily available from other sources, and are chiefly of interest to direct participants. However, this effort may prove to be a pioneering one in that a basis for establishing a multidisciplinary attack on both oceanographic and living resource problems of the oceans, by the coopera-

tive effort of a number of nations, is in the making. From this point of view the success of the cooperative effort is most important. The living resources of the tropical Atlantic are subject to a rapidly growing harvest by both coastal and noncoastal states; therefore the investigation of these resources should be a joint responsibility of these states.

APPENDIX A

THE INTERNATIONAL COOPERATIVE INVESTIGATION OF THE TROPICAL ATLANTIC

Prepared by Vernon E. Brock, International Coordinator, ICITA

BACKGROUND

In early 1961, two programs were proposed for oceanographic and fishery studies in the Gulf of Guinea:

1. A study of the demersal fisheries off the west coast of Africa, by the Commission for Technical Cooperation in Africa, South of the Sahara (CCTA).

2. An investigation of the pelagic fishes of the Gulf of Guinea by the Bureau of Commercial Fisheries (BCF).

Each proposal included plans for supporting physical, chemical and marine biological studies. When a request for support to the Agency for International Development (AID) by CCTA brought its program to the attention of the Bureau of Commercial Fisheries, it was proposed that the CCTA and BCF investigations be carried out cooperatively. In late 1961, at a meeting in Lagos, Nigeria, the details of cooperation between these programs were formulated.

The Bureau's proposed program was presented to and accepted by the Inter-Agency Committee on Oceanography and approved by the National Academy of Sciences Committee on Oceanography.

In February, 1962, the BCF held a meeting of oceanographers from the eastern United States to determine their interest in a cooperative investigation of the waters of the Tropical Atlantic. At this meeting a high level of interest was apparent, augmented plans for research were developed, and it was proposed that these be submitted to the Intergovernmental Oceanographic Commission (IOC) for consideration as an international effort.

The plans were presented to the Bureau of the IOC in April, 1962, and at the suggestion of this Bureau the U.S. Department of State issued an invitation to interested Member Nations and activities of the IOC to send representatives to a Working Group Meeting in Washington, D.C. The representatives met in June, 1962, and developed plans for the International Cooperative Investigations of the Tropical Atlantic (ICITA) which were adopted at the Second Session of the IOC in Paris in September, 1962. Nomination of Mr. V. E. Brock of the Bureau of Commercial Fisheries as International Coordinator by members of the International Coordination Group for the ICITA was approved by the Secretariat of the IOC.

The ICITA plans developed at the Working Group Meeting in June, 1962, and adopted by the IOC involves mid-winter and mid-summer, multiple vessel, synoptic surveys of the Tropical Atlantic, from Africa to South America and from 18° N to 18° S latitude. The first of these two surveys, designated as EQUALANT I, was scheduled to start on February 15, 1963; the second, EQUALANT II, on August 1, 1963.

EQUALANT I involves two 15-day synoptic surveys; separated by a 15-day period. EQUALANT II will involve one 15-day, multiple vessel, synoptic survey.

Fourteen vessels from seven nations are scheduled to participate in EQUALANT I. These include five from the United States (CHAIN, CRAWFORD, EXPLORER, GERONIMO and OREGON), three from the Soviet Union (LOMONOSOV, ZVEZDA and OLONEZ), two from Brazil (BAEPENDI and BERTIOGA) and one each from Argentina (A.R.A. COMODORO LASERRE), Republic of Ivory Coast (REINE POKOU), Nigeria (KIARA), and Republic of Congo, Brazzaville (OMBANGO). See Figure 1 for vessel tracks, EQUALANT I.

It is anticipated that 16 vessels from 10 nations will participate in EQUALANT II. These include five from the United States (ALAMINOS, GERONIMO, PILLSBURY and possibly the HORIZON and one U. S. Coast Guard vessel, three from the USSR, one each from Republic of Ivory Coast, Nigeria, Republic of Congo (Brazzaville) and possibly one each from Brazil, Argentina, Spain, Japan and Poland.

In brief, the plans for the programs common to all vessels call for oceanographic stations to

2000 meters, with observations to the bottom at 120 mile intervals. Standard observations from all of the 14 participating vessels during the 15-day periods include:

1. Temperature, salinity, oxygen and phosphate at each depth sampled at each station;

2. Measurement of the rate of primary productivity using the Carbon 14 isotope technique and measurement of the standing crop of zooplankton at least once each day; and

3. Surface meteorological observations (upper air observations from selected vessels).

In addition to the observations common to each vessel, a number of oceanographic, biological, and geophysical programs will be carried out by scientists from activities operating the vessels or by scientists from other United States and foreign oceanographic laboratories who will be working aboard the vessels.

UNITED STATES PARTICIPATION IN THE ICITA

Research Vessel Commitments

EQUALANT I (February 15 to March 18, 1963)

Five United States vessels are scheduled to participate in EQUALANT I; the CHAIN and CRAWFORD (Woods Hole Oceanographic Institution), GERONIMO and OREGON (Bureau of Commercial Fisheries) and the EXPLORER (U.S. Coast and Geodetic Survey). As may be seen from Figure 1, the GERONIMO will work in the Gulf of Guinea, the EXPLORER in the central area, the CHAIN and CRAWFORD in the western sector and the OREGON in the waters off the northeast Coast of Brazil.

Special requirements imposed by various research programs aboard these vessels and logistical considerations will result in some deviations by individual ships from the schedules and plans as proposed by participants in the IOC Working Group Meeting.

EQUALANT II (August 1 to August 15, 1963)

Three U.S. vessels, GERONIMO (Bureau of Commercial Fisheries), ALAMINOS (Texas A & M) and PILLSBURY (University of Miami) are firmly committed to participate in EQUALANT II; two others are tentatively committed, the HORIZON (Scripps Institution of Oceanography) and an as yet undesignated vessel operated by the U.S. Coast Guard. Various U.S. Government and University activities, other than those directly concerned with vessel operations, will participate in the ICITA.

CONTRIBUTIONS OF PARTICIPATING ORGANIZATIONS

U. S. WEATHER BUREAU (USWB)

Marine Unit

Surface Observations - Surface meteorological observations will be assembled from each vessel (standard six-hour observations forwarded through Radio Central) and from other sources in the ICITA area (merchant vessels and shore stations) for preparation of daily forecasts. These forecasts will be transmitted to participants each day by the USWB. Where necessary, instruments will be provided, vessel personnel instructed, and log sheets and instruction manuals forwarded to each vessel. Weather Bureau observers will be assigned to the EXPLORER, GERONIMO and CHAIN. Subsequent to the ICITA field operations, the USWB will prepare daily summary charts of selected parameters for publication in the ICITA Atlas.

Upper Air Observations - The upper air observing program includes NWSC supported pibal installations of the GERONIMO and CHAIN and ONSF supported radio-sonde observations from the EXPLORER. The Weather Bureau observer aboard each of these three vessels will be assisted by a member of the scientific party.

National Weather Satellite Center

Special Cloud Observations - Observations of clouds, including a simple sketch of high, middle and low cloud layers and related data, are to be made daily from each vessel. During daylight hours these observations will be made at time of TIROS satellite transits over the ICITA area. Supplemental cloud photographs will be taken by the USWB observers for correlation with aircraft and satellite photographs.

Sea Surface Radiation Measurements - Six vessels will be provided with Suomi-Kuhn radiometers to measure long wave radiation from the sea surface.

Airplane Overflights - Overflights of the ICITA area by fully instrumented USWB

hurricane reconnaissance airplanes are scheduled during the first synoptic period of EQUALANT I (provided that a TIROS satellite is in operation). Two DC-6 type planes will fly parallel tracks 300 miles apart from Recife to Dakar and return the following day. If TIROS operations permit, an extra flight may be made from Dakar over the ICITA area prior to the return to Recife.

BUREAU OF COMMERCIAL FISHERIES (BCF)

Vessel Operation: EQUALANT I - GERONIMO and OREGON

EQUALANT II - GERONIMO

In an effort to standardize biological data, the Bureau of Commercial Fisheries provided each participating vessel with all necessary equipment and supplies for the determination of primary productivity and measurements of the standing crop of the zooplankton. Arrangements are being made for performing the essential Beta counting services for the primary productivity measurements and for determination of the displacement volume of each zooplankton sample.

Mr. Vernon E. Brock, Director, Bureau of Commercial Fisheries Biological Laboratory, Washington, D.C., was approved by the IOC Secretariat as the International Coordinator for the ICITA. His duties, as defined in a resolution adopted by the IOC, include, in part, "coordinating and advising concerning schedules and programs of observations . . . keeping all participants of the ICITA and interested organizations informed . . . assisting, where practicable, in procurement, loan and exchange of equipment . . . convening meetings of the International Coordination Group and implementing the assembly and preparation of the data resulting from the ICITA for publication and preparation and publication of the Atlases."

U. S. COAST AND GEODETIC SURVEY (USC&GS)

Vessel Operation: EQUALANT I - EXPLORER

Bathymetry - Plotting sheets and instructions for their use were prepared by the USC&GS for use aboard each participating vessel, both U.S. and foreign. It is anticipated that following the field surveys these plotting sheets will be assembled by the NODC and copies provided to WDC/A and WDC/B.

Drift Cards - Several thousand drift cards were prepared by the USC&GS for release from the ICITA vessels. Each card, laminated in plastic, carries instructions printed in English, French, Portuguese, Spanish and Russian.

Tidal Data - The Tide Section of the USC&GS will assemble all tide data from stations in the ICITA survey area for the period of the investigations. These data will be prepared for publication, as applicable, in both the Data Reports and the Atlas.

Radio Central - The EXPLORER will serve as radio central during EQUALANT I. The communication capabilities aboard the vessel were considerably augmented by the USC&GS for the purpose. Instructions for transmitting the encoded surface weather and upper air observations, as prepared through coordinated effort of the USWB, USC&GS, USCG, USAF, and NODC, were distributed to each vessel. The daily forecasts for the survey area, prepared by the USWB, will be received from NSS Washington and re-broadcast from the EXPLORER.

NATIONAL OCEANOGRAPHIC DATA CENTER (NODC)

The NODC, at the request of the International Coordinator, assumed responsibility for assembly and shipment of various encoding forms for oceanographic data, coding manuals, BT log sheets and instructions, meteorological reporting forms and manuals, plotting sheets for navigational purposes, and instructions for selected standardized observations. (Translated into French, Spanish and Russian by the Department of State.) Sets of each of the above were furnished to each participating vessel.

In cooperation with the USC&GS, the NODC arranged the communication plan and schedules for use during EQUALANT I. In addition to the arrangements for communications among radio central (EXPLORER) and the other vessels, arrangements were made with Captain L. Capurro of the Argentine Hydrographic Office for transmission to the NODC of the data from at least one complete oceanographic station each day. Vertical sections of temperature, salinity, density and oxygen will be maintained as these data are received via teletype through the Potomac River Naval Command.

It was proposed by the participants in the June Working Group Meeting that the NODC

assemble, exchange and publish the data from both EQUALANT I and II, and prepare and arrange for publication of the ICITA Atlas. A proposal for review by the International Coordination Group (the "Editorial Board") is in preparation.

U. S. NATIONAL MUSEUM (USNM)

A scientist from the USNM, working from the GERONIMO, will collect and preserve fishes (shipboard trawl hauls, night lighting, and shore collections) for return to the National Sorting Center. All zooplankton samples collected during the 15-day synoptic periods are to be shipped to the Bureau of Commercial Fisheries, Biological Laboratory, Washington, D.C. After determination of displacement volumes, these samples will be sent to the National Sorting Center, USNM, for sorting, identification of organisms, and preparation of lists of such identifications.

AGENCY FOR INTERNATIONAL DEVELOPMENT (AID)

Funds were provided by AID for support of the CCTA Trawling Campaign and for purchase of oceanographic equipment for use aboard the REINE POKOU (Republic of the Ivory Coast) and the KIARA (Nigeria).

U. S. NAVY OCEANOGRAPHIC OFFICE (USNOO)

The USNOO assisted in preparation of the salinity samples for use in intercalibrating the data from analyses made aboard the participating vessels, provided bathymetric charts for use aboard the vessels and prepared and printed a compilation of charts depicting the distribution of various oceanographic properties in the ICITA area.

U. S. COAST GUARD

Vessel Operation: undesignated vessel in EQUALANT II (commitment not firm).

DEPARTMENT OF STATE

The United States State Department arranged clearance for U.S. vessels to operate in territorial waters of foreign nations, expedited, through arrangements with American Embassies, the shipment and delivery of equipment to the participating foreign laboratories and vessels, and translated instructions for various types of observations and sampling techniques, common to each vessel, into French, Spanish and Russian.

NON-GOVERNMENTAL ORGANIZATIONS

Vessel Operation:

Woods Hole Oceanographic Institution - CHAIN and CRAWFORD in EQUALANT I

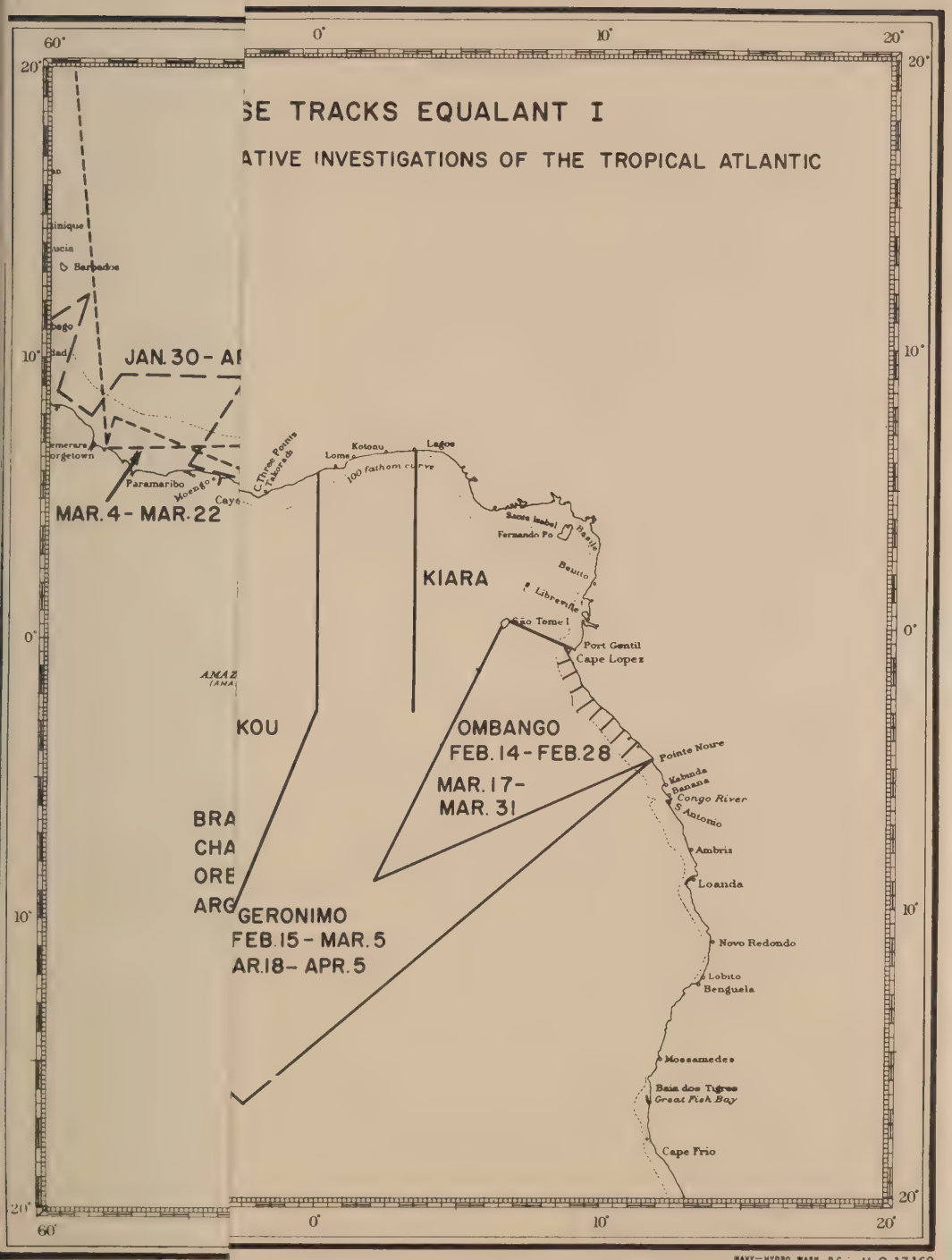
Texas A & M - ALAMINOS in EQUALANT II

University of Miami - PILLSBURY in EQUALANT II

Scripps Institution of Oceanography - HORIZON in EQUALANT II (commitment not firm).

U.S. scientists from Bingham Oceanographic Laboratory, Yale University, Institute of Marine Sciences of the University of Miami, New York University, Scripps Institution of Oceanography, and Johns Hopkins University will undertake various oceanographic, marine biological, geological, and geophysical programs aboard the U.S. vessels. Oceanographers from Texas A & M will participate aboard the Argentine vessel A.R.A. COMODORO LASERRE.

The details of programs summarized above relate primarily to EQUALANT I (February - March, 1963). Preliminary plans for EQUALANT II (August 1963) were prepared by participants in the June IOC Working Group Meeting. Preliminary plans and schedules are now in preparation; some final details must await consideration of results from EQUALANT I.



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PESTICIDES—A NEW FACTOR IN COASTAL ENVIRONMENTS

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Chemical control of unwanted organisms is not new, actually dating back at least as far as the days of the Greeks. It is only within the last decade, however, that the use of pesticides has increased to the point that they must now be reckoned a significant factor in the environment of fish and wildlife. The era of the new pesticides, principally organic compounds, can be said to have started during World War II with the widespread application of DDT for control of insects affecting man's health and comfort. Soon thereafter this material was being used against agricultural and forest pests, and a host of new pesticides was being developed.

The possibilities of damage to non-target organisms were recognized at the outset, and studies were conducted by the U. S. Fish and Wildlife Service and other Federal agencies, and by various State agencies and private organizations and individuals. Early and generally limited research in coastal environments, or with the animal inhabitants of these areas, was reported by Ginsburg (1945), Sandholzer (1945), Cottam and Higgins (1946), Nelson and Surber (1947), Loosanoff (1947), Tiller and Cory (1947), and Goodrum et al. (1949). A more detailed study was conducted by Springer and Webster (1951). Most of the early work, however, was concerned with inland areas, and it is only recently, with greater awareness and funds, that increasing attention has been focused on our important coastal resources.

During the past five years, the Bureau of Commercial Fisheries, Fish and Wildlife Service, has stressed laboratory investigations of the relationship between pesticides and coastal fish and shellfish. Initially, these studies were conducted concurrently at four regional laboratories with emphasis on separate animal groups in each area. More recently the program has been consolidated in Florida, and separate projects are conducted as the need arises in different geographic locations. Unless otherwise stated, the laboratory findings reported in this paper have resulted from the Bureau's work in Florida (Butler, 1963).

[1]Now leader, Cooperative Wildlife Research Unit, South Dakota State College, Brookings.

Today the total area in the United States treated annually with chemical pesticides is estimated to be nearly 200 million acres. Applications to any given tract may vary from as few as 1 every several year for forest insect control to as many as 50 or more a year for adult mosquito control. It is estimated that about 90 million acres are treated annually for chemical insect control (Hall, 1962), and chemical weed control is practiced on 90 million acres of agricultural land alone (Shaw, in press).

In addition, large areas receive applications of chemicals for control of non-agricultural weeds, plant diseases, and other pests. These are not all different acres, however. New areas are continually being treated as the upward trend in pesticide use continues, and as new outbreaks of pests occur. Moreover, treatment is not necessarily restricted to the intended area. Pesticides applied from the air can be carried by the wind, often for miles. Even when they reach the ground they are subject to further movement, some being caught up again by the wind in dust, others being washed away into streams and rivers in solution, or when absorbed on soil particles. This is in addition to chemicals that are applied directly to coastal marshes and bays for control of mosquitoes, flies, weeds, and other pests.

The persistence of many of the chlorinated hydrocarbon insecticides is well known, but not as well understood is the fact that some may last 10 years or more (Lichtenstein and Polivka, 1959). Until recently, the organic phosphorus insecticides were of little concern in this respect because of the ease with which they undergo hydrolysis and presumably become innocuous. It has been found, however, that even some of these, such as parathion, may contaminate watersheds for as long as 9 months after orchard applications (Nicholson et al., 1962). Analyses show that parathion was transported by runoff and concentrated in lowlands and pond muds.

Whether parathion and other chemicals eventually reach the sea in significant quantities remains to be learned. However, studies by the U. S. Public Health Service show that most of the major rivers sampled since 1957 are carrying at least trace amounts of certain pesticides (Middleton and Lichtenberg, 1960). The presence of DDT—5 parts per billion (p.p.b.) in water, 40 p.p.b. in endemic trout—in a presumably uncontaminated coastal stream in Alaska indicates some possibilities of movement.

The reaction of estuarine animals and plants to pesticides, although sometimes direct and obvious, is more often ill-defined and far from understood. This results in part from the various modes of action of these chemicals. A pesticide may be directly toxic, either over a short

or a long period, or it may exert an indirect influence through reduction of lower food-chain organisms or other modification of the habitat. A secondary toxic influence occurs when pesticides applied at low rates are concentrated in successively greater amounts in their passage through the food chain until they reach a level that is poisonous to predatory higher forms of animal life. Considerable species and individual differences exist in tolerance to the various pesticides. Consequently, results are not necessarily predictable on the basis of work with related compounds; usually each chemical must be evaluated.

Laboratory and Field Toxicity Studies

Phytoplankton

Previous investigations by Ukeles (1960) showed that the floating microscopic marine plants are extremely sensitive to the substituted urea herbicides including monuron, diuron, and neburon and cannot tolerate concentrations as low as 0.5 p.p.b. There has been particular concern that many of the other pesticides might seriously affect this phytoplankton, which forms the broad base of the food chain and is much more important in coastal environments than in fresh water.

Phytoplankton productivity can be measured by adding known amounts of radiocarbon to samples and determining the amount of carbon fixed in the cells after a definite interval under constant light conditions. This technique has been used in the laboratory to evaluate the effects of a large number of the most important chemical pesticides. Most of the chlorinated hydrocarbons, including DDT, heptachlor, chlordane, aldrin, and toxaphene, decreased productivity by 50 to 90 per cent when present at a concentration of 1 part per million (p.p.m.) for 4 hours. The organophosphorus compounds, as a rule, are much less toxic, as are also the herbicides, except for the substituted ureas. For example, at a concentration of 1 p.p.m., 2-4-D and its derivatives had little effect on productivity. The few fungicides that have been tested, however, are as toxic as the chlorinated hydrocarbons.

Crustaceans

Because shrimp, crabs, and other crustaceans are arthropods, like the insects, they understandably are sensitive to many of the chemical insecticides. Concentrations of heptachlor, endrin, and lindane in the range of 0.3-0.4 p.p.b. killed or immobilized half of the adult commercial brown and pink shrimp exposed in 48-hour laboratory tests. Other chlorinated hydrocarbons, including DDT, chlordane, toxaphene, and dieldrin, showed similar effects at 1-6 p.p.b. In the laboratory, paralyzed individuals may live for days or even weeks, but in the struggle

for survival in the sea this condition results almost immediately in death.

Juveniles of the blue crab, important not only for its commercial but also for its sporting value, are about 100 times more resistant than shrimp to the chlorinated hydrocarbon insecticides in laboratory tests. The stone crab is intermediate in susceptibility (Butler, 1962).

Few organophosphorus compounds have been tested on crustaceans. These materials show various degrees of toxicity but one, Bayer 29493, (Baytex®),[1] used in mosquito control, is the most toxic pesticide tested to date on shrimp and crabs in the laboratory. Herbicides are of relatively low toxicity to crabs. However, mud crabs, perhaps because of their small size, were irritated by 2,4-D at a concentration of only 1 p.p.b. (Butler, 1962). Few herbicides have been tested on shrimp.

Field studies[2] of DDT as used in aerial mosquito control in tidal salt marshes at rates as low as 0.2 lb/A corroborate the high sensitivity of crustaceans (Springer and Webster, 1951; Springer, 1961). Isopods and amphipods were nearly extirpated and showed no population recovery even 1 to 2 years later. Prawns, or grass shrimp (*Palaemonetes*), used as fish bait, were somewhat less susceptible. Populations of blue crabs were reduced 10 to 40 per cent when exposed to single treatments of DDT at 0.3 lb/A and 95 to 97 per cent when these treatments were repeated 3 to 10 times a year for several years. Fiddler crabs were generally more resistant than blue crabs. George et al. (1957), however, obtained contradictory findings on the relative susceptibility of fiddler and blue crabs to DDT.

Field studies with other chemicals showed BHC (100 per cent gamma isomer equivalent) and dieldrin to be more toxic than DDT to blue and fiddler crabs (Springer, 1961). An experimental treatment of 0.3 lb/A of dieldrin for greenhead fly control killed many of these crustaceans (Jamnback and Wall, 1959), and a treatment of 1 lb/A for sandfly control caused complete annihilation without any evidence of population recovery for at least the next 4 months (Harrington and Bidlingmayer, 1958).

Because of their habits and low toxicity tolerance, the commercial shrimp are particularly susceptible to pesticidal poisoning. After hatching in offshore waters the young, which usually are more sensitive than the adults, spend several months in the upper reaches of estuaries and bayous where they are nearer most sources of pesticidal pollution and, thus, doubly vulnerable. Extensive contamination of the environment could have serious repercussions since, collectively,

[1]Reference to trade name does not imply Government endorsement of a product.

[2]Throughout the paper the field applications referred to were made in accordance with recommended practice or registered use, unless otherwise stated.

shrimp make up the Nation's most valuable fishing product in terms of revenue yield (Power, 1962). A number of shrimp in an estuarine stream of coastal South Carolina died after heavy rains presumably washed in heptachlor applied 6 days previously to adjoining land at 0.25 lb/A for imported fire ant control. This stream occurs in an area upon which 60 per cent of the State's shrimp production depends (personal communication, Robert Lunz, April 10, 1962). Also, shrimp in bait pens along the Florida and Texas coasts were killed by DDT or BHC applied for mosquito control (deSylva, 1954; Chin and Allen, 1957).

Mollusks

Pesticidal effects on oysters, clams, and mussels may be less obvious. The adult forms being sedentary cannot flee from pesticide-contaminated areas. Their reaction in the face of high concentrations is to close their shell, sometimes for as long as a week or two, thereby stopping feeding and growth. Metabolism is increased during the summer, however, forcing them to open sooner than they would at lower temperatures, and to possibly acquire a lethal dose. At lower concentrations, oysters may fail to pump water or grow at their usual rate, even though they stay open and feed to some extent (Butler et al., 1960).

The chlorinated hydrocarbons are the most toxic pesticides tested in the laboratory. They cause a 50 per cent decrease in shell growth in 96 hours at concentrations ranging from 0.007 to 0.5 p.p.m. depending on the chemical used. Lindane, organophosphorus and carbamate insecticides, and herbicides were much less toxic. Loosanoff et al. (1957) found that larvae of oysters were considerably more susceptible than adults to DDT; all larvae died in 96 hours at 1 p.p.m.

When oysters, whose growth rates had been decreased by pesticides, were returned to unpolluted sea water, they recovered their normal growth rates within 2-4 weeks. The length of the recovery period had no apparent relation to the severity of the toxic effects of the more than 30 different chemical pesticides tested.

In the field, single or repeated applications of DDT at dosages of 0.2-0.8 lb/A (and experimentally up to 1.6 lb/A) and of aldrin at 0.2 lb/A for mosquito control in tidal salt marshes had no apparent adverse effect on adults of various species of snails and mussels (Springer and Webster, 1951; Springer, 1961). Populations of salt-marsh snails (*Melampus bidentatus*) actually increased after DDT treatment, possibly because of control of some limiting factor.

A 0.3-lb/A experimental application of dieldrin for greenhead fly

control did not appear to harm snails (Jamnback and Wall, 1959). Three months later nearly all of the horse mussels in the treated plot were dead, but a significant amount of halogenated hydrocarbon was not found in the tissues of living mussels, either shortly after treatment or 5 months later. There were no visible detrimental effects on snails and oysters from a 1-lb/A application of dieldrin for sandfly control (Harrington and Bidlingmayer, 1958).

Fish

The two species of marine fish studied in the laboratory show a relative pattern of response to the various groups of pesticides similar to that exhibited by the plankton, crustaceans, and mollusks. They are somewhat more resistant than shrimp. Half of the juvenile striped mullet tested were generally killed in 48 hours by chlorinated hydrocarbons at concentrations ranging from 0.0004 to 0.007 p.p.m. BHC, Mirex, Kepone,® lindane, and methoxychlor were the principal exceptions, requiring concentrations from 10 to 100 times greater. The longnose killifish was slightly more resistant than the striped mullet.

DDT at 0.2-0.6 lb/A for mosquito control caused considerable distress (but apparently low mortality) among killifishes and tidewater silversides in tidal salt marshes, whether applied only once, or monthly for 3 months. Fairly heavy losses occurred at 0.8 lb/A, particularly in shallow ponds not subject to regular tidal flushing (Springer and Webster, 1951). Dieldrin at 0.2 lb/A (experimental) killed many fish in salt marshes (Ginsburg and Jobbins, 1954) and at 1 lb/A, as registered for sandfly control, caused substantially complete mortality (Harrington and Bidlingmayer, 1958). Repopulation by some but not all species was completed 10 weeks later. No mortality among fish in salt marshes was observed from applications of BHC (100 per cent gamma isomer equivalent) and aldrin, each at rates of 0.2 lb/A (Springer, 1961). A treatment of 0.5 lb/A of malathion killed a third of the killifish held in artificial containers (Darsie and Corriden, 1959).

The potential significance of pesticides to certain fin fish is illustrated by the fact that large numbers of young menhaden concentrate in restricted parts of estuaries during their first year of life (June and Chamberlin, 1958). The annual commerical catch of this species in the United States exceeds that of any other fish (Power, 1962). Mullet, spot, and other species sought by both commercial and sport fishermen spend part of their lives in tidal estuaries. The killifishes, so common in coastal marshes, aid in control of the same mosquitoes for

which some pesticidal programs are intended, and, in addition, are taken for use as fish bait.

Reptiles and Amphibians

Diamondback terrapin in tidal streams were not outwardly affected by mosquito control programs involving application of DDT at experimental rates as high as 1.6 lb/A and of BHC (100 per cent gamma isomer equivalent) at 0.2 lb/A (Springer, 1961). Similarly, leopard frogs in brackish meadows survived treatments of BHC (100 per cent gamma isomer equivalent) at 0.2 lb/A and dieldrin at the experimental rate of 0.2 lb/A.

Birds

Birds, too, apparently were not directly affected by BHC (100 per cent gamma isomer equivalent) and aldrin at 0.2 lb/A and experimental treatments of DDT at 1.6 lb/A and of dieldrin at 0.25 lb/A (Springer, 1961). However, a week-old clapper rail died about 2 days after application of DDT at 0.3 lb/A (Springer and Webster, 1951). Analysis of the tissues showed 112 p.p.m. of DDT, which probably was obtained through consumption of poisoned fiddler crabs. Fiddlers that died following repeated applications of DDT at 0.2 lb/A contained 2.2-46 p.p.m. of DDT (Mills, 1952).

These crustaceans compose as high as 90 per cent of the summer diet of clapper rails in New Jersey. Obviously, any sizable reduction in crustacean numbers because of pesticidal applications could have a profound indirect influence on the population and production of clapper rails. Other birds, including various species of herons, gulls, terns, swallows, and sparrows, increased or decreased in abundance in accordance with the availability of food that remained after mosquito control treatments. Ginsburg and Jobbins (1954) reported some birds were killed within 3 days after an experimental application of dieldrin in granules at 0.2 lb/A. Whether birds eat these granules is unknown.

That birds inhabiting coastal areas are becoming contaminated with pesticides is shown by the results of collections of waterfowl along the Gulf in Texas in 1961 (Crabtree, 1963). Over half of the individuals examined were carrying residues of DDT and related compounds in their bodies. Although they probably picked up some pesticides during their migrations south and north, it is entirely conceivable that some came from chemicals that were applied for mosquito control in the area or that washed or drifted in from other areas. The effects of these pesticidal burdens on bodily processes are only poorly understood. However, recent studies in California show that DDT and dieldrin

applied as seed treatments for control of rice insects significantly reduced the survival of young pheasants (Hunt and Keith, 1963).

Mammals

The few studies that have been made show that mammals in coastal marshes were not outwardly affected by chemical applications for mosquito control. Marked meadow voles and rice rats survived treatments of BHC (100 per cent gamma isomer equivalent) at 0.2 lb/A and dieldrin at the experimental rate of 0.2 lb/A (Springer, 1961). No affected mammals were found after experimental applications of DDT as high as 1.6 lb/A (Springer and Webster, 1951). Stearns et al. (1947) found that spraying of DDT at 0.2 lb/A and Paris green at experimental rates as high as 4 lb/A did not appear to harm muskrats.

SPECIAL PROBLEMS

Chronic Toxicity

Ordinarily, because of rapid dilution rates, high pesticidal concentrations are not to be anticipated in estuaries. Therefore it is of interest to note the reaction of typical animal inhabitants to continuous exposure to low levels. Juvenile clams were subjected to DDT (1 p.p.b.) and dieldrin (5 p.p.b.); oysters and mussels were subjected to aldrin (2 p.p.b), malathion (2 p.p.m.) and toxaphene (50 p.p.b.); and spot were subjected to dieldrin at concentrations of 0.1, 0.01 and 0.001 p.p.b. Exposure periods ranged from 3 to 6 months. Animals were maintained in running sea water to which the pesticide was continuously added. Under these conditions it was found that mortality and growth rates were nearly identical in experimental and control groups. Experimental oysters became sexually mature and spawned at the same time as the controls.

The unfiltered sea water supplying these aquaria contained planktonic larvae. Large numbers of these benthic animals, including at least 25 species in 7 phyla, set fortuitously and grew equally well in experimental and control aquaria.

However, not all of the observations were so reassuring. There was definite evidence of distortion of the vertebral column in many of the experimental, but in none of the control fish. Unfortunately, growth rates of both experimental and control spot were appreciably lower than expected, perhaps because of an inadequate food supply. This work is being repeated and expanded to clarify the results.

Resistance

There is a growing body of evidence to show that insects and some freshwater vertebrates, such as mosquitofish (*Gambusia affinis*) (Vin-

son et al., 1963) and cricket frogs (*Acris*) (Boyd et al., 1963), are developing resistance after exposure to pesticides. Presumably, this occurs through the breeding of resistant individuals. It was of interest, therefore, to determine if any resistance had developed in the mollusks and fish used in the chronic toxicity experiments described in the previous section. When these experimental oysters were subjected again to toxic concentrations of the several pesticides, growth rates immediately were halved and it was obvious that no resistance had appeared.

However, the spot again reacted differently. In a test with dieldrin, all untreated control fish from the long exposure experiment died in 24 hours when exposed to a presumed minimum lethal concentration, whereas only 20 per cent of the fish previously exposed to low concentrations died. Whether this acquired resistance is permanent or temporary will be studied in future tests.

Biological Concentration

The mechanisms for concentrating pesticides in the estuarine environment are being investigated now under controlled laboratory conditions. The well-known ability of the oyster to extract and accumulate heavy metals and petroleum products present in only trace quantities in the sea water makes them especially suitable as test animals. Oysters have been observed to concentrate zinc, for example, at a level about 170,000 times that in the surrounding water (Chipman et al., 1958).

Oysters exposed to DDT at 0.5 p.p.m. in relatively small aquaria were found to remove more than 50 per cent of the chemical from the surrounding medium within 6 hours and 96 per cent in 2 days. Under these conditions, much of the DDT is adsorbed in the intestinal contents and excreted. Fecal deposits were found to have approximately 35 times the concentration of DDT originally present in the water. A relatively large percentage of the DDT was also retained in the oyster body tissues. Experiments are continuing to determine under what conditions, and for how long, the oyster will retain this pesticide.

The fact that the oyster and other filter-feeding bottom forms, such as mussels and clams, may concentrate and fix these chemicals in their fecal deposits is a matter for additional concern. The non-selective bottom feeders, such as the marine worms, are important links in many of the estuarine food chains and may, in turn, accumulate the pesticides to an extent lethal to their predators, including the fish and crustaceans that provide food for man and certain birds that are taken as game and later eaten. Thus, in the sea, there is the possibility

of a continuous recycling and concentration of the more stable pesticidal compounds until they pose a real threat to man's own welfare. This problem has received little attention in marine environments so far. However, large biological build-ups of pesticidal residues through the food chain have been noted in freshwater areas. Original applications of 0.014-0.02 p.p.m. of TDE (DDD) in water were eventually concentrated in fatty tissue to peak levels of 2500 p.p.m. in fish and 1600 p.p.m. in fish-eating birds (Hunt and Bischoff, 1960).

Habitat Modification

The most obvious effects of pesticides are toxicological. But there are indirect effects that can be at least as destructive. One of these, discussed previously, is reduction of lower food-chain organisms. Another is modification of the vegetative environment by herbicides. Beaven et al. (1962) showed that aquatic weed control programs, such as those for Eurasian watermilfoil (*Myriophyllum spicatum*), will kill oysters, clams, and possibly fish and crabs when large amounts of decaying vegetation deplete the oxygen content of the water, producing an anaerobic condition. Non-specific herbicides applied for control of certain weeds may also kill desirable plants in the treated area or outside of it when transported by currents.

Solutions

Recognition of the persistence of pesticidal residues in the environment and the sensitivity of non-target animals has greatly stimulated the search for less hazardous control measures. The introduction of any foreign chemical agent into the environment constitutes some degree of pollution that is fundamentally undesirable. Our overall objective must be to devise controls that are more specific, and here there are signs of progress.

Many biological control procedures are inherently specific. Methods now being explored include development of species-specific bacterial diseases and wider application of sterilization techniques, such as those used successfully in controlling screw-worm populations.

Specificity in chemical control is needed also. Pesticides are available that are definitely less hazardous to non-target animals than those now in use, even though some of them may be less easily applied and possibly more expensive. For example, ryania could be substituted for toxaphene in the control of the cane borer in Mississippi delta sugar fields. Similarly, certain organophosphorus compounds kill mosquitoes at levels that are not known to be toxic to fish or to tadpoles (Mulla et al., 1963). These compounds also reduce the probability of

biological concentration because, as a rule, they hydrolyze rapidly. This characteristic of rapid disappearance is important in preventing damage to non-target species. Powerful sex attractants may bring the pest to the poison without endangering other species. Baits that are attractive to the target organism and less so to other animals also can be useful; such baits are being tried for imported fire ant control.

Most promise for effective pest control with least damage to wildlife and fish lies in carefully planned integrated programs. It has been shown that a well-designed attack that includes the careful use of pesticides with the use of other methods can provide control that is as effective, safer, and less costly than chemical applications alone (Pickett, 1961). We look forward with confidence to the development of techniques that will more adequately preserve our coastal environments.

SUMMARY

Pesticides are used so widely now that they must be reckoned a significant factor in the environments of fish and wildlife. Increasing attention is being devoted to study of their effects on important coastal resources. Chemicals may be directly toxic or exert an indirect influence through reduction of food-chain organisms or modification of the habitat. Another mode of action is biological concentration in successive food-chain organisms. Information is summarized on the known effects of pesticides on coastal life from plankton to mammals. Toxicity varies greatly among different organisms and chemicals. Some marine forms appear to be unaffected by recommended or registered pesticidal applications while others are susceptible to poisoning at concentrations of a fraction of a part per billion. Use of less persistent chemicals that are more specific for individual pests and less toxic to non-target organisms offers promise for the future, particularly when integrated with physical and biological methods of control.

LITERATURE CITED

Beaven, G. Francis, Charles K. Rawls, and Gordon E. Beckett
1962. Field observations upon estuarine animals exposed to 2,4-D. Proceedings of the Northeastern Weed Control Conference 16:449-458.

Boyd, Claude E., S. Bradleigh Vinson, and Denzel E. Ferguson
1963. Possible DDT resistance in two species of frogs. Copeia 1963(2):426-429.

Butler, Philip A.
1962. Effects on commercial fisheries. Effects of Pesticides on Fish and Wildlife: A Review of Investigations during 1960. Fish and Wildlife Service, Circular No. 143. p. 20-24.
1963. Commercial fisheries investigations. Pesticide-Wildlife Studies: A Review of Fish and Wildlife Service Investigations during 1961 and 1962. Fish and Wildlife Service, Circular 167, p. 11-25.

Butler, Philip A., Alfred J. Wilson, Jr., and Alan J. Rick
1960. Effect of pesticides on oysters. Proceedings of the National Shellfisheries Association 51:23-32.

Chin, Edward, and Donald M. Allen
1957. Toxicity of an insecticide to two species of shrimp, *Penaeus aztecus* and *Penaeus setiferus*. Texas Journal of Science 9(3):270-278.

Chipman, Walter A., Theodore R. Rice, and Thomas J. Price
1958. Uptake and accumulation of radioactive zinc by marine plankton, fish and shellfish. Fish and Wildlife Service, Fishery Bulletin 135, Volume 58: 279-292.
Cottam, Clarence, and Elmer Higgins
1946. DDT: Its effect on fish and wildlife. U. S. Fish and Wildlife Service, Circular 11. 14 p.
Crabtree, D. Glen
1963. Wildlife studies—Denver Wildlife Research Center. Pesticide-Wildlife Studies: A Review of Fish and Wildlife Service Investigations during 1961 and 1962. Fish and Wildlife Service, Circular 167, p. 43-73.
Darsie, Richard F., Jr., and F. Eugene Corriden
1959. The toxicity of malathion to killifish (Cyprinodontidae) in Delaware. Journal of Economic Entomology 52(4):696-700.
deSylva, Donald P.
1954. The live bait shrimp fishery of the northeast coast of Florida. Florida Board of Conservation, Technical Series No. 11. 35 p.
George, John L., Richard F. Darsie, Jr., and Paul F. Springer
1957. Effects on wildlife of aerial applications of Strobane, DDT, and BHC to tidal marshes in Delaware. The Journal of Wildlife Management 21(1):42-53.
Ginsburg, Joseph M.
1945. Toxicity of DDT to fish. Journal of Economic Entomology 38(2):274-275.
Ginsburg, Joseph M., and Daniel M. Jobbins
1954. Research activities in chemical control of mosquitoes in New Jersey in 1953. Proceedings Forty-first Annual Meeting New Jersey Mosquito Extermination Association and Tenth Annual Meeting American Mosquito Control Association, p. 279-291.
Goodrum, Phil, W. P. Baldwin, and John W. Aldrich
1949. Effect of DDT on animal life of Bull's Island, South Carolina. The Journal of Wildlife Management 13(1):1-10.
Hall, David G.
1962. Use of insecticides in the United States. Bulletin of the Entomological Society of America 8(2):90-92.
Harrington, Robert W., Jr., and William L. Bidlingmayer
1958. Effects of dieldrin on fishes and invertebrates of a salt marsh. The Journal of Wildlife Management 22(1):76-82.
Hunt, Eldridge G., and Arthur I. Bischoff
1960. Inimical effects on wildlife of periodic DDD applications to Clear Lake. California Fish and Game 46(1):91-106.
Hunt, Eldridge G., and James O. Keith
1963. Pesticide-wildlife investigations in California, 1962. Proceedings Second Annual Conference on the Use of Agricultural Chemicals in California. University of California, Davis. 29 p.
Jamnback, Hugo, and William Wall
1959. The common salt-marsh Tabanidae of Long Island, New York. New York State Museum and Science Service, Bulletin Number 375. 77 p.
June, Fred C., and J. Lockwood Chamberlin
1958. The role of the estuary in the life history and biology of Atlantic menhaden. Proceedings of the Gulf and Caribbean Fisheries Institute Eleventh Annual Session: 41-45.
Lichtenstein, E. P., and J. B. Polivka
1959. Persistence of some chlorinated hydrocarbon insecticides in turf soils. Journal of Economic Entomology 52(2):289-293.
Loosanoff, V. L.
1947. Effects of D. D. T. upon setting, growth and survival of oysters. Fishery Gazette 64(5):94, 96.
Loosanoff, Victor L., J. E. Hanks, and A. E. Ganaros
1957. Control of certain forms of zooplankton in mass algal cultures. Science 125 (3257):1092-1093.
Middleton, Francis M., and James J. Lichtenberg
1960. Measurements of organic contaminants in the Nation's rivers. Industrial and Engineering Chemistry 52(6):99A-102A.
Mills, H. R.
1952. Death in the Florida marshes. Audubon Magazine 54(5): 285-291.
Mulla, M. S., L. W. Isaak, and H. Axelrod
1963. Field studies on the effects of insecticides on some aquatic wildlife species. Journal of Economic Entomology 56(2):184-188.
Nelson, Arnold L., and Eugene W. Surber
1947. DDT investigations by the Fish and Wildlife Service in 1946. U. S. Fish and Wildlife Service, Special Scientific Report No. 41. 8 p.
Nicholson, H. Page, Hubert J. Webb, Gerald J. Lauer, Robert E. O'Brien, Alfred R. Grzenda, and Donald W. Shanklin
1962. Insecticide contamination in a farm pond. Transactions of the American Fisheries Society 91(2):213-222.
Pickett, A. D.
1961. Pesticides and the biological control of arthropod pests. Presented at the Northeast Wildlife Conference, Halifax, Nova Scotia, June 11-14, 1961. 7 p. + 2 p. tables.

Power, E. A.
1962. Fishery statistics of the United States, 1960. Fish and Wildlife Service, Statistical Digest No. 53. 529 p.
Sandholzer, Leslie A.
1945. The effect of DDT upon the Chesapeake Bay blue crab (*Callinectes sapidus*). Fishery Market News 7(11):2-4.
Shaw, W. C.
Unpub. Advances in weed control research. To be published in the proceedings of the Fifteenth Annual California Weed Conference, Santa Barbara, California. January 21-23, 1963.
Springer, Paul Frederick
1961. The effects on wildlife of applications of DDT and other insecticides for larval mosquito control in tidal marshes of the eastern United States. Ph.D. thesis, Cornell University, xii + 185 p. (Abstract in Dissertation Abstracts 22(6): 1777).
Springer, Paul F., and John R. Webster
1951. Biological effects of DDT applications on tidal salt marshes. Mosquito News 11(2):67-74.
Stearns, L. A., E. E. Lynch, B. Krafchick, and C. W. Woodmansee
1947. Report of the use of DDT and Paris green on muskrat marshes. Proceedings of the Thirty-fourth Annual Meeting of the New Jersey Mosquito Extermination Association: 82-95.
Tiller, R. E., and Ernest N. Cory
1947. Effects of DDT on some tidewater aquatic animals. Journal of Economic Entomology 40(3):431-433.
Ukeles, Ravenna
1960. Effects of several toxicants on five genera of marine phytoplankton. Presented at 1960 Convention of National Shellfisheries Association. [Data given in Effects of Pesticides on Fish and Wildlife: A Review of Investigations during 1960. Fish and Wildlife Service, Circular No. 143. p. 21 and Table 10 (1962).]
Vinson, S. Bradleigh, Claude E. Boyd, and Denzel E. Ferguson
1963. Resistance to DDT in the mosquito fish, *Gambusia affinis*. Science 139(3551): 217-218.

OCEAN CONDITIONS IN THE VICINITY OF THE ALEUTIAN ISLANDS, SUMMER 1957

by
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ABSTRACT

Data collected by Canadian, Japanese and United States vessels
ring the summer of 1957 are utilized to describe the physical
eanography of the Aleutian Islands region.

A brief review of the bottom topography, tidal currents and
matology of the region is given.

Vertical and lateral sections of temperature, salinity and sigma-t
e shown and their significance discussed.

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INTRODUCTION

As part of the International North Pacific Fisheries Commission (INPFC) program of research on the high-seas distribution and abundance of salmon, the Bureau of Commercial Fisheries initiated, in 1955, the collection of oceanographic data in the Bering Sea-North Pacific region.

Since that time, spring and summer surveys have been made each year. The 1955 and 1956 cruises were conducted by the University of Washington under contract to the Bureau. The data reports for those years have been compiled by Favorite and Love (1957) and Love (1957, 1959).

Since 1957 the data have been collected and processed by USFWS personnel (Favorite and Pedersen, 1959a, 1959b). This report is based on the oceanographic cruises of Canadian, Japanese and United States vessels during the period July 19–August 31, 1957. Most of the measurements were made from the USFWS vessels *Attu*, *Paragon* and *Pioneer*.

Dissolved oxygen and inorganic phosphate measurements were made aboard some of the vessels; however, the observations were too few to permit separate analysis of these parameters.

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DESCRIPTION OF THE REGION

The terms " region " or " area " encompass 45°N.–56°N. latitude, 150°W.–175°E. longitude. The terms "Aleutian Islands " and "Aleutian Chain " are used to include the arc of islands from Unimak to Attu. "Aleutian ridge " refers to the submerged sections between the islands. In citing positions the terms " latitude " and " longitude " will usually be omitted.

The Coast Pilot for Alaska (U. S. Coast and Geodetic Survey, 1955) provides such information as local weather conditions and tidal currents, in the vicinity of the Alaska Peninsula and Aleutian Islands. Fleming (1955) has reviewed the general features of the area and has included an extensive bibliography.

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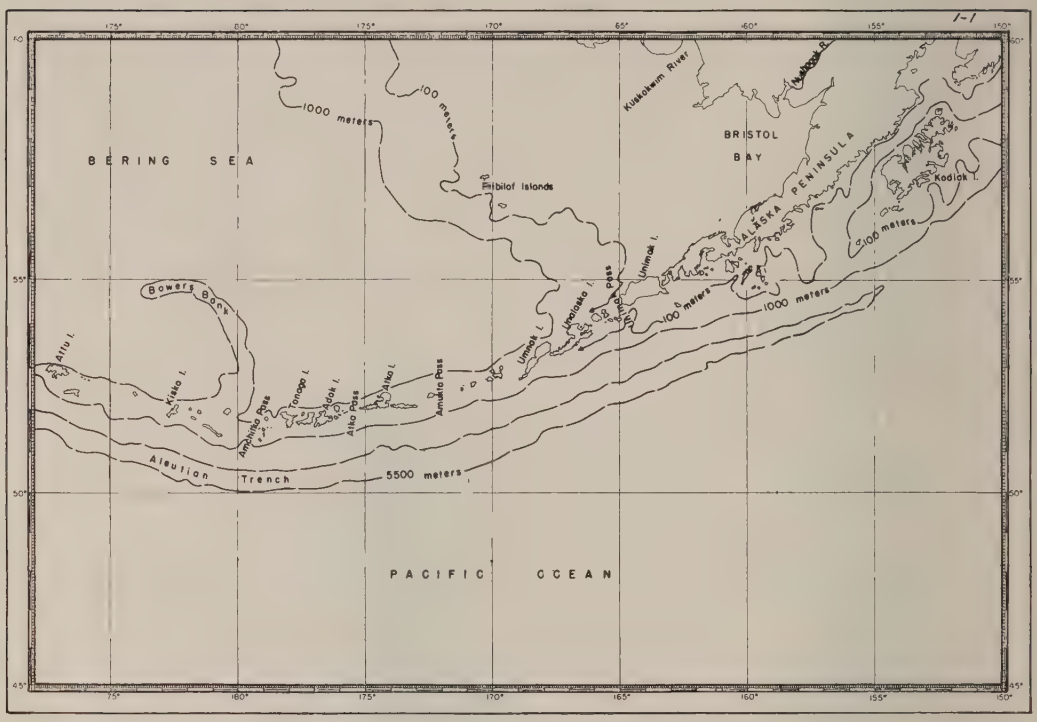


FIGURE 1. Chart of the Aleutian Island area.

Figure 1 gives the names of the principal islands and passes in the Aleutian Chain. The 100, 1,000, and 5,500 meter isobaths are also shown.

In the Bristol Bay region, there is a broad, shallow shelf which extends westward of the Pribilof Islands. The 100-meter contour is not drawn in the Aleutian region since it nearly coincides with the 1,000-meter contour.

The Aleutian Islands rise precipitously from depths of greater than 7,000 meters in the Aleutian Trench and greater than 3,500 meters in the Bering Sea. As may be seen, the 1,000-meter contour is quite close to the Islands with the exception that at the 180° meridian it extends into Bering Sea enclosing Bowers Bank, where depths of less than 130 meters are reported. It is noted that on some charts the name " Bowers Bank " refers only to a shallow bank (less than 100 fathoms) situated at about 54° 25′N., 179° 45′E.

Only Amchitka Pass (179°W.) is deep enough to allow exchange of waters at depths exceeding 1,000 meters.

Tidal Currents

Tidal currents in the region are, according to the Coast Pilot (*op. cit.*), ". . . highly complex, making generalizations impossible. . . . All passages in the Aleutian Islands have strong currents. In the nar Akun Strait, the current is reported to reach a velo of 12 knots."

In southeastern Bering Sea, north of Unimak Isla Hebard (1959) observed the tidal currents in Ju 1957, by means of an Ekman current meter, for offshore and two inshore stations. Measurem were made at the surface, top and bottom of thermocline and the bottom. The flow of the aver current was counter-clockwise. At the offshore. 56′N., 164° 30′W.; 57° 40′N., 161° 53′W.) stati dextrally rotating tidal currents occurred with a m mum of between 1.0 and 1.5 knots flowing paralle the coast. The inshore (56° 37′N., 160° 59′W.; 40′N., 163° 24′W.) stations exhibited rotary t currents, with varying degree of rotation; the m mum currents were between 0.8 and 1.7 knots para to the coast.

Weather

Quoting further from the Coast Pilot: " weather of the Aleutians is characterized by persist ly overcast skies, high winds, and violent storms. other area in the world is recognized as having w weather in general than that which the Aleut Islands experience."

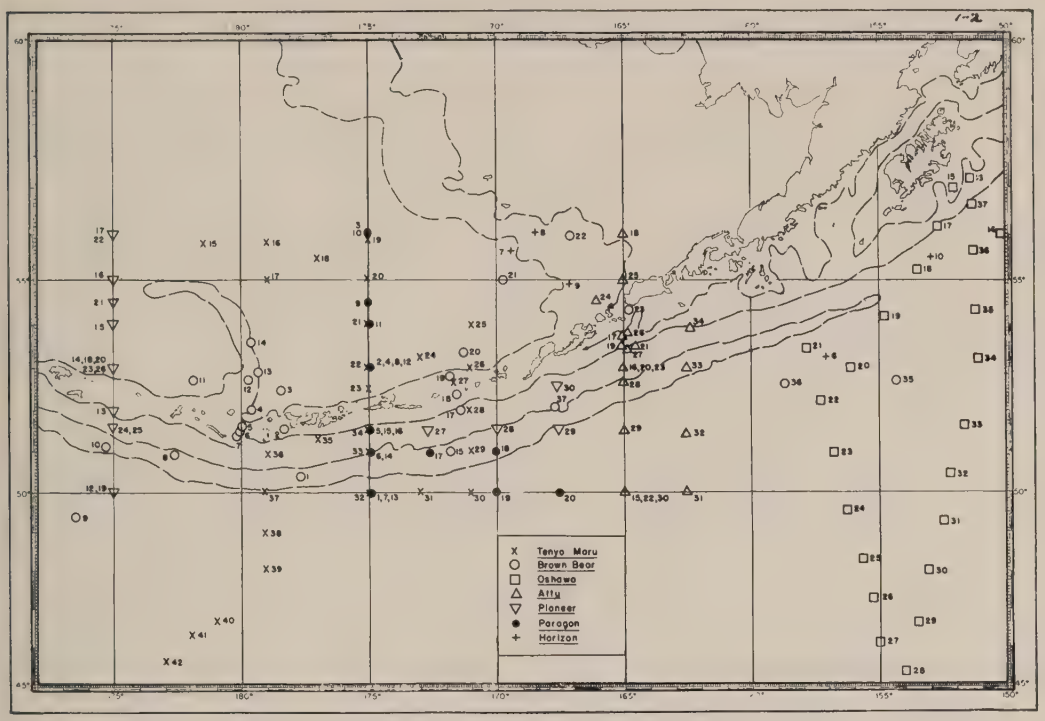


FIGURE 2. Station positions, July 19—August 31, 1957.

Winds in the Aleutian region are generally influenced by the Aleutian Low which fills in during May and gradually loses its identity through June and July. By August the Low appears in the north Bering Sea, becoming stronger with the winter months.

Winds in May have a northwesterly or westerly component. During the summer months the prevailing winds are from the south or southwest.

Evaporation

Jacobs (1951) has prepared mean charts which show evaporation in the area as being 0–0.05 cm./day for the period June–August. Precipitation minus evaporation is shown as about 15–20 cm. for the season.

Dilution

Fresh water is also added to the region by runoff and ice melt. In Bering Sea, the Yukon and Kuskokwim Rivers, and in Bristol Bay, the Ugashik, Egegik, Naknek, Kvichak and Nushagak Rivers contribute heavily to the runoff. On the south central coast of Alaska, the Copper and Susitna Rivers supply much of the fresh water runoff. In addition, there are numerous streams and small rivers which add to the net dilution of Bering Sea and Subarctic[1] waters.

Ice breakup in the Nushagak, Kuskokwim and Susitna Rivers begins, on the average, early in May.

SOURCES AND TREATMENT OF DATA

Reports Utilizing 1957 Data

The location of the stations used is shown in Figure 2.

Not all of the data from the aforementioned cruises were utilized. Some stations were outside the area under investigation. Other stations were occupied before or after the period of July 19–August 31.

Dodimead (1958) has discussed the 1957 horizontal distribution of properties in the Gulf of Alaska. He has also described the vertical section based upon *Oshawa* stations 16 and 28–37 (see Fig. 2).

Kitano (1958) has presented horizontal and vertical sections based on the 1957 cruise of the *Tenyo-maru* and a preliminary report on oceanographic conditions observed from the MV *Attu*, *Paragon* and *Pioneer* has been presented by Favorite in INPFC (1959). Aron (1959) has utilized 1957 *Brown Bear* data in a paper

[1] The term " Subarctic waters " is used in this paper to describe that portion of the North Pacific Ocean where the salinity minimum is at the surface. " Subpolar " will include Bering Sea, Bristol Bay and Subarctic North Pacific waters.

Table 1. Sources of data.

Vessel	Abbreviation (Used in vertical sections)	Period (1957)	Stations used	Authority
Attu	A	19 Jul.–23 Aug.	14–34	Favorite and Pedersen (1959 a)
Paragon	Pn	21 Jul.–31 Aug.	1–20	" " " "
Pioneer	P	21 Jul.–31 Aug.	12–30	" " " "
Brown Bear	B	9–29 Aug.; 30 Jul.–2 Aug.	1–23[1]; 35–37	R. H. Fleming and Staff (1958)
Horizon		27 Jul.–8 Aug.	6–10	Scripps Institution of Oceanography[2]
Oshawa		30 Jul.–11 Aug.	14–37	Pacific Oceanographic Group (1957)
Tenyo-maru	T	19–30 Jul.	14–42	Hokkaido Regional Fisheries Laboratory (1958

[1] Brown Bear station 16 was omitted in the data report. Prefixes to Brown Bear station numbers omitted here and in Figure 1.

[2] Manuscript of physical and chemical data collected on the *Mukluk* expedition by Scripps Institution of Oceanography.

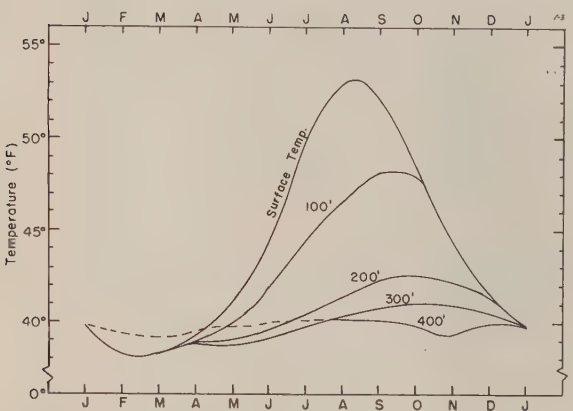


Figure 3. Time series of mean temperature (°F.) for the area 50°N.—55°N.; 160°W.—165°W.; from Robinson (1957).

dealing with midwater trawling in the North Pacific and Bering Sea.

Selection of Time Period

Figure 3 is taken from Robinson (1957). The curve showing surface temperature indicates that the rate of change of temperature from July 20 to September 1 is negligible. Fleming (1955) has presented a time-series cycle of temperature representing the degree square 52°–53°N., 178°–179°E. The surface temperature peak is shown as about August 10.

The temperature-salinity (T-S) diagrams for several locations have been presented in INPFC (1959), and are reproduced here as Figures 4 to 6. It is immediately apparent from the diagrams that the period of summer heating of the surface waters has continued into late August. The surface waters have generally become more dilute as the season progressed.

The T-S diagrams, then, show that for the upper water column the vertical and horizontal sections of temperature, salinity and sigma-t will include seasonal effects. Ideally, one would like to be able to repre the temperature field when the rate of change of t perature is nearly zero for the time period covered.

Changes in the water column below about meters will be due primarily to advection and no the direct influence of external processes. Thi apparent from the temperature cycle shown in Fig 3 which reveals a considerable lag in the diffusio heat from the surface to deeper water.

In contouring the various fields it is assumed t the oceanographic stations were occupied synoptica In lieu of a synoptic survey it is advisable to sele time period when oceanic conditions are as nea being stationary as possible. With regard to t perature, the period July 19–August 30 provides least rate of change. For this reason some ea data collected by USFWS vessels and the Japa vessel *Oshoro-maru* were not used.

Averaging of Data

Some stations were occupied several times. W this occurred interpolated data at standard de were averaged[2], the resulting values being used in sections. In some instances, where the depth of Nansen bottle casts reached different depths, only data in the upper 150–300 meters were averaged

To remove the undetermined effects of inte wave activity, each station should be occupied m than once. If data from only a few stations are a aged, the stations occupied only once will, presuma assume more importance than they should. Tak average values of, for example, surface temperatur 53°N., 175°E. (Fig. 4), puts the temperature in middle of the upward slope of the time-series cu (Fig. 3). If the last station occupied at a given lo

[2] Temperature and salinity average values were used to ob an average sigma-t.

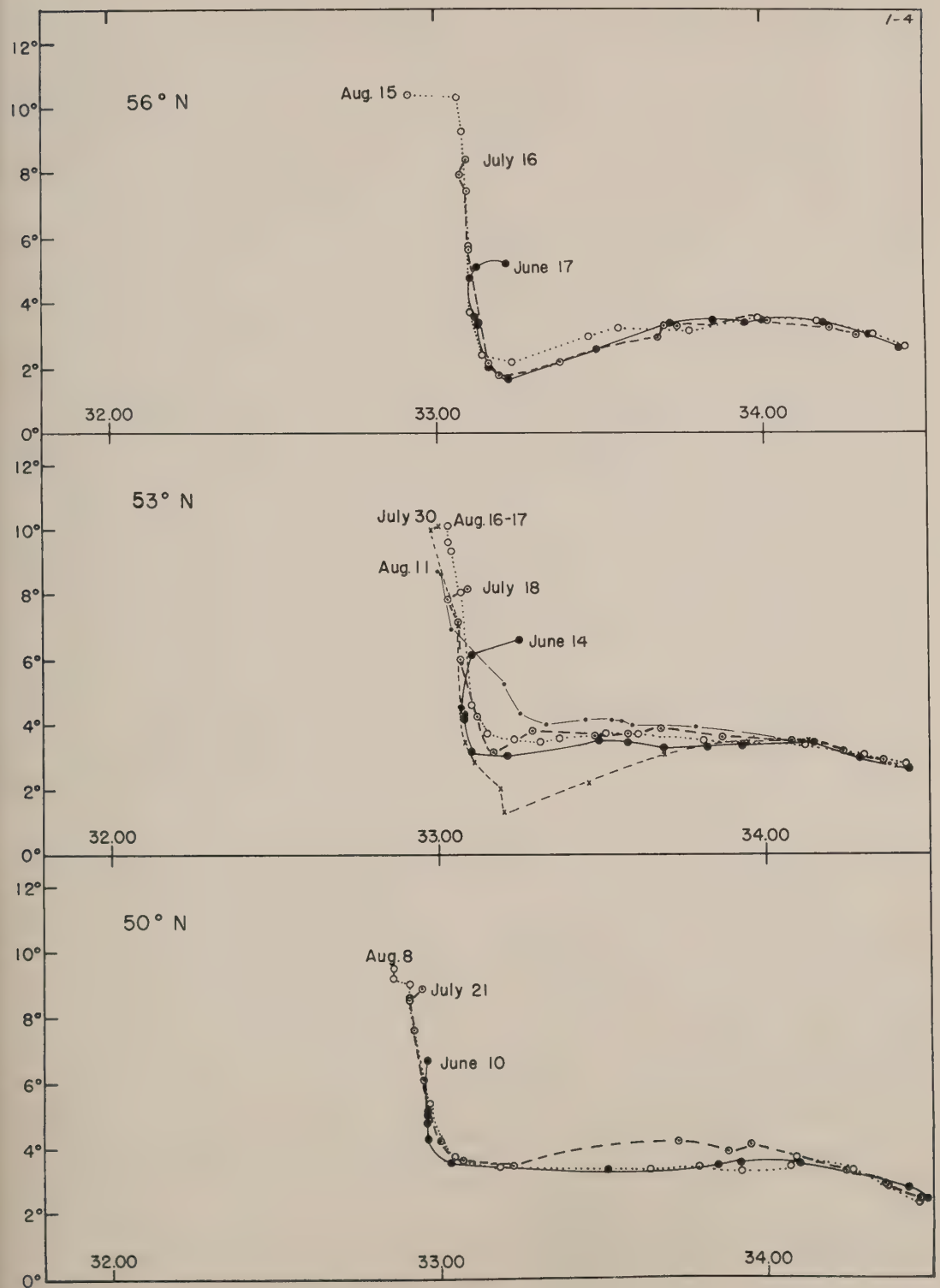


FIGURE 4. T-S curves, 175°E., June—August, 1957.

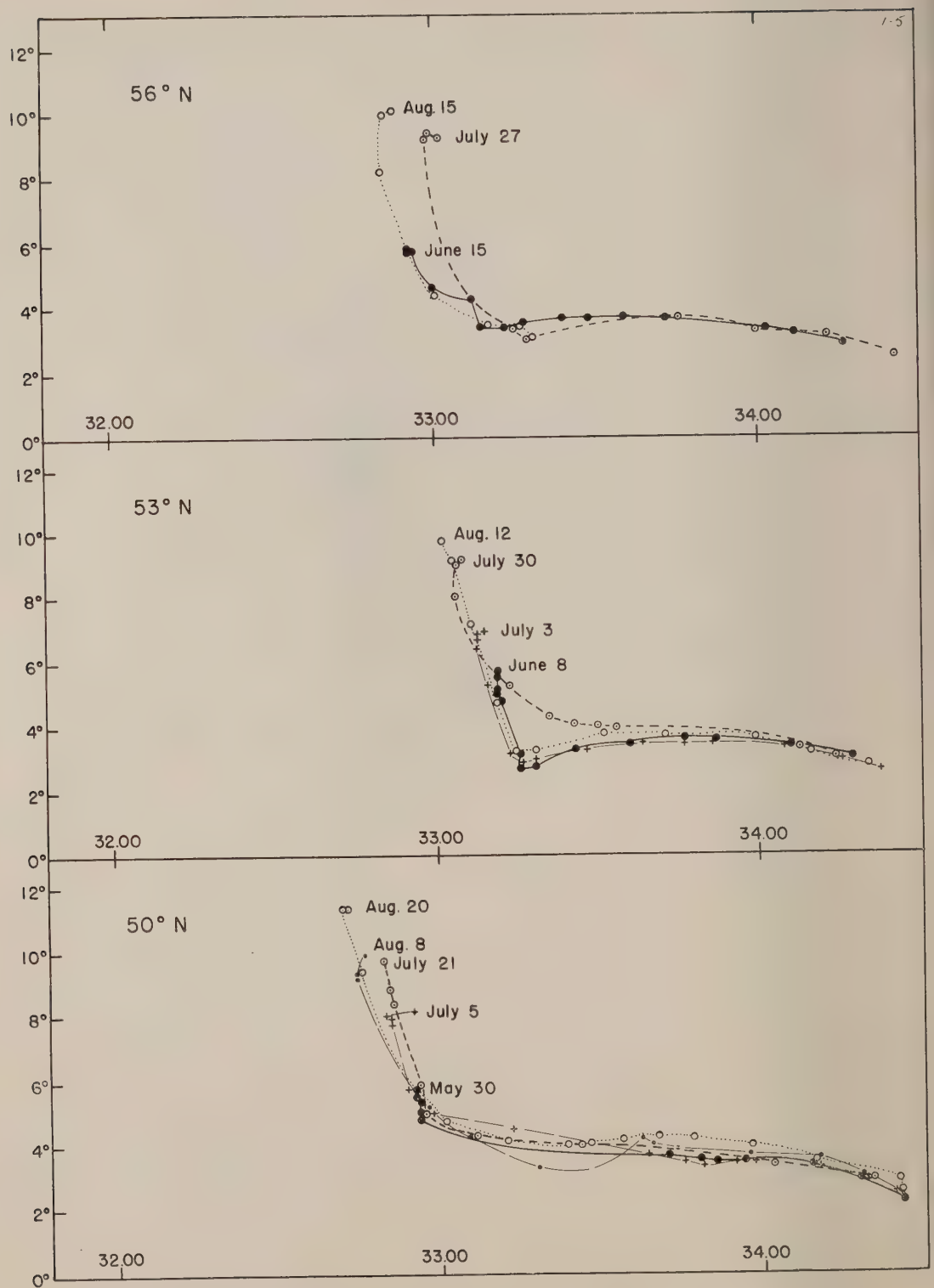


FIGURE 5. T-S curves, 175°W., May—August, 1957.

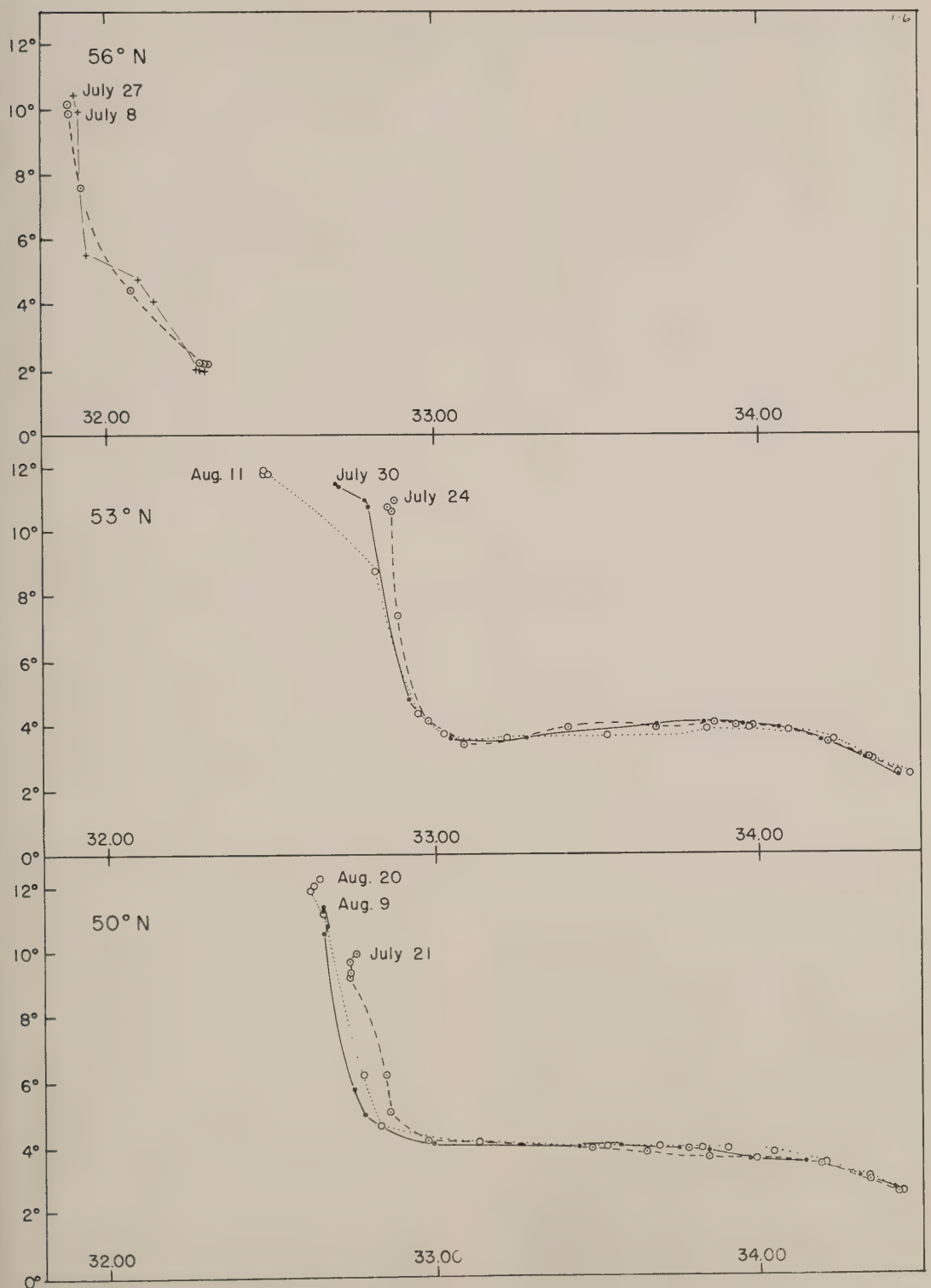


FIGURE 6. T-S curves, 165°W., July—August, 1957.

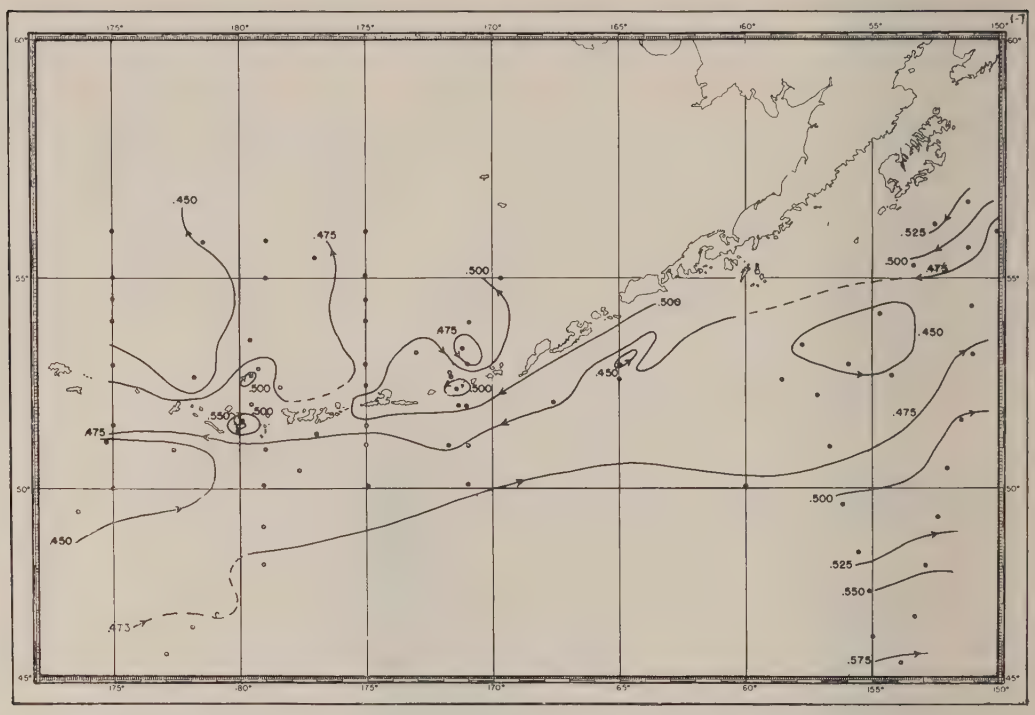


FIGURE 7. Anomaly of geopotential topography, 0/300 db. Points indicate station positions.

tion were used, further bias would be provided because adjacent, single stations may have been occupied at different times on the cycle.

SOURCES OF DATA

The sources of data utilized, details of salinity analytical methods and treatment of data will be found in the references cited in Table 1.

CURRENTS

As an introduction to this section a brief discussion of the method of determining geostrophic currents is presented. The geostrophic equation is a familiar one in meteorology and oceanography. The assumption is made that the magnitude of inertial and frictional forces is much less than the magnitude of the horizontal pressure gradient force and the apparent force due to the earth's rotation (Coriolis force). Geostrophic velocities and transports are calculated from the balance of the latter two forces.

Charts of the anomaly of geopotential topography show geostrophic current directions in the form of isolines of dynamic height. The velocities are proportional to the spacing of the isolines, in a narrow latitude range. Dynamic height calculations are made for each oceanographic station by integration of the anomaly of specific volume (the differe of the observed volume per unit mass from a mass of water at 0°C., 35‰ salinity and at the served pressure) from a reference level to the des depth. It is assumed that motion at the refere level is negligible.

The surface current pattern relative to the 300 ibar (approximately 300 meters) level is shown Figure 7. The choice of the 300 db. level is no imply that this is a level of no motion, but was m because not enough stations could be used if a dee level were selected. A shallower level would be s ject to short term external influences. As will shown in a discussion of the vertical sigma-t sect near the islands there is a large pressure gradien 300 meters and deeper, which implies considera motion at the reference level. Nevertheless, it is that the current directions as shown in the figure representative. The magnitude of the mean flow (the spacing of the contours) cannot be considere very close approximation.

It is apparent that the currents are related to bot topography. A region bounded by 0.475 dyna meters lies over the Aleutian Trench. The cur flowing east, north of Attu and Kiska Islands, is flected north by Bowers Bank. The currents n

l south of the Aleutian Islands follow the 1,000-
ter isobaths. In the vicinity of Unalaska Island,
: currents have a northward component. The cur-
ıt charts of Barnes and Thompson (1938) and Good-
ın *et al.* (1942), show northward flow between the
) and 1,000-meter isobaths that lie west of the
ibilof Islands.

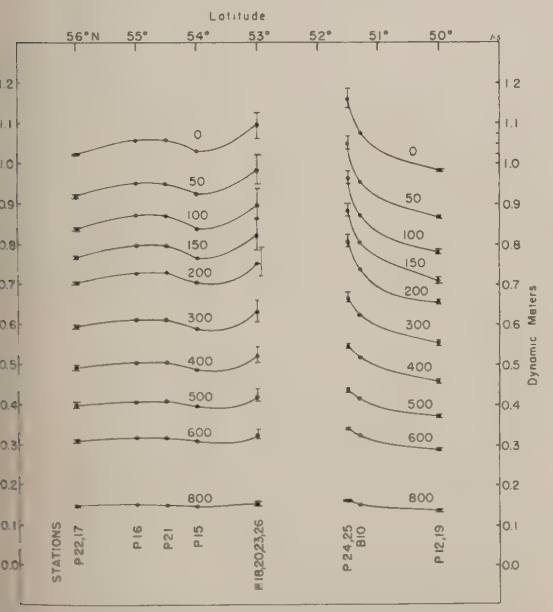
The westward flow along the south of the islands is
e primarily to surface accumulation of fresh water
ong the Alaska Peninsula. This flow would be
alogous to the estuarine-type circulation proposed by
ılly and Barber (1960).

The abovementioned relation between surface flow
d the Aleutian Trench is only incidental to the cur-
ıt pattern. If the Aleutian Trench does influence
rculation in the region this influence is probably
nfined to the deep circulation.

The station spacing in the vicinity of Bowers Bank
es not allow conjecture on the possibility of a leeside
ave. Sverdrup *et al.* (1942) have pointed out that
e expected deflections due to bottom topography
ay be masked by synoptic surveys.

EOPOTENTIAL HEIGHTS

In two water columns with the same temperature
r salinity) distribution, the less saline (or warmer)
lumn will have a higher steric level. The integrated



GURE 8. Geopotential anomaly of the isobaric surfaces in dynamic meters relative to the 1,000 db. surface along 175°E. longitude, August, 1957. Points indicate averaged values. Range of dynamic heights shown by vertical bars.

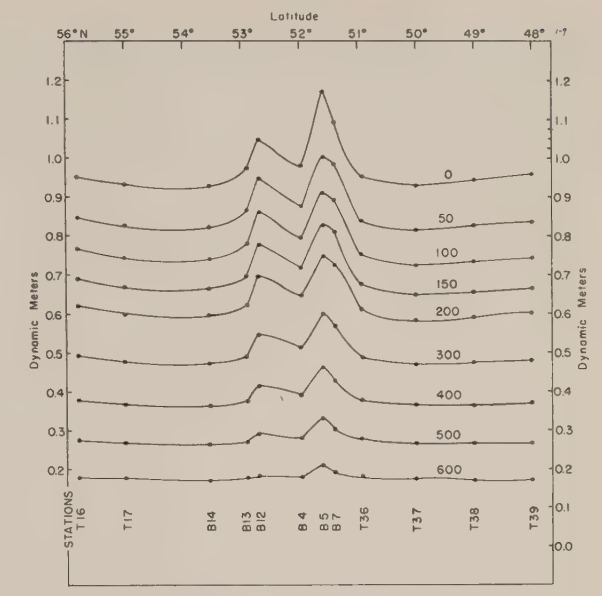


FIGURE 9. Smoothed geopotential anomaly of the isobaric surfaces in dynamic meters relative to the 800 db. surface along 179°W. longitude, July—August, 1957. Points represent averaged values.

effect of temperature and salinity on the potential energy distribution in a water column with reference to an assumed level surface is shown by charts of geopotential anomaly. In order to determine the relative influence of either temperature or salinity on steric levels, calculations must be made of thermal and haline departures, since the steric departure from a reference sea level is nearly equal to the algebraic sum of thermal and haline departures[3].

Figure 8 shows the geopotential anomaly of the isobaric surfaces relative to the 1,000-db. level along 175°E. longitude. The range of the isobaric levels is indicated by vertical lines. If one considers the surface isobaric level from 50°–51°30′N. and from 53°–54°30′N., the average dynamic level north of the Islands is higher than to the south, approximately 1.065

[3] Pattullo *et al.* (1955) define the thermal (Z_T) and haline (Z_S) departures as follows:

$$Z_T = g^{-1}\int_{p_a}^{p_o} \frac{\partial\alpha}{\partial T}\,\triangle T\,dp$$

$$Z_S = g^{-1}\int_{p_a}^{p_o} \frac{\partial\alpha}{\partial S}\,\triangle S\,dp$$

where

α = Specific volume anomaly,
T, S = temperature, salinity, respectively,
g = acceleration due to gravity,

and the integration is from atmospheric pressure to a pressure where all seasonal effects are assumed to vanish.

versus 1.010 dyn. m. The average dynamic height at 51°30′N. is 0.064 dyn. m. greater than at 53°N.

Figure 9 shows the surfaces relative to 800 db. The large variations in the vicinity of Amchitka Pass have been interpreted in Figure 7 as isolated cells.

The meridional isobaric surfaces along 175°W. are shown in Figure 10. The situation adjacent to the Islands is the reverse of that along 175°E. The dynamic level at 52°30′N. is 10.9 dyn. cm. greater than at 51°30′N.

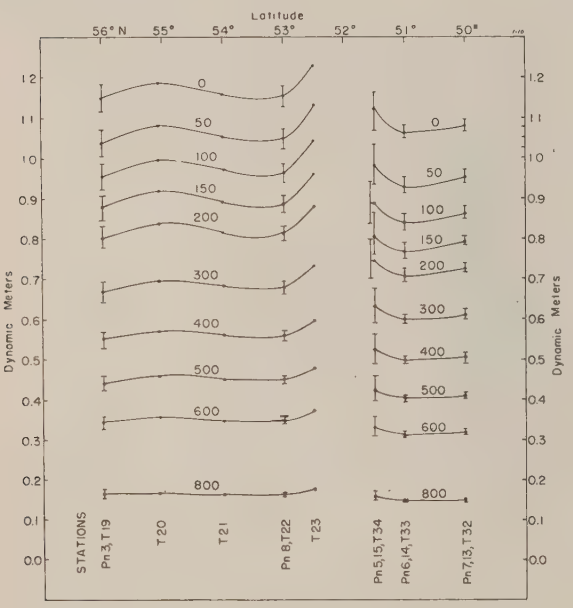


FIGURE 10. Geopotential anomaly of the isobaric surfaces in dynamic meters relative to the 1,000 db. surface along 175°W. longitude, July—August 1957. Points indicate averaged values. Range of dynamic heights shown by vertical bars.

As in the vertical sections of salinity and sigma-t, the geopotential sections bring out the fact that dilution in Bering Sea decreases westward, and that the Aleutian Chain acts as a barrier separating the saline[4] waters of the Pacific Ocean from the Bering Sea. The effect of cooler temperature in reducing steric levels increases westward. This is shown along 175°E. longitude. At 51°30′N. and 53°N., the salinity distribution in the water columns is nearly the same but the steric level south of the Aleutian ridge is greater than north of it.

LATERAL DISTRIBUTION OF SIGMA-T

Charts showing the variations with depth of a particular value of sigma-t provide a three-dimensional view of subsurface circulation, in that currents tend to be parallel to isolines of sigma-t. Lateral mixing greatest intensity takes place in the surface of consta potential density[5] and the flow patterns are more sta and simpler than those on a horizontal surface (Mo gomery, 1938).

Near the Islands and in the island passes, n isentropic mixing occurs and the principles of is tropic analysis do not apply. In the use of isentro analysis, one assumes that the effects of viscosity a vertical diffusion are negligible.

The reader should keep in mind that looking dow stream the sigma-t surface deepens to the observe right (in the Northern Hemisphere).

Figures 11 and 12 show the depth of, and salin on, the 26.0 sigma-t surface. Immediately south the Islands at about 165°W., there is a tongue (meters) that flows along the south of the Islan becoming shallower to the west.

There is a shallow (less than 25 meters) layer s rounding the Islands from about 171°W. to 170 The sigma-t curves indicate a movement of wa through Amchitka Pass into the Bering Sea, althou this is a region of non-isentropic mixing.

In the Bering Sea, the depth of the surface decrea northward to 25 meters. The cell of greater than meters at 173°W. is based on a single observation 70 meters.

Figures 13 and 14 show the depth of, and salin distribution on, the 26.5 sigma-t surface. T surface deepens rapidly when one approaches the lands from the south. The depth chart indica that between 125–150 meters there is a steady moti that sweeps the entire length of the Aleutian Cha Again, there is a ridge extending east-west bound by the 125 meter contour. In the eastern part the figure the ridge penetrates into the upper 1 meters.

Several anticyclonic cells are present near t Islands, and a single large cyclonic cell is situat to the east.

In the Bering Sea, the depth of the surface decrea to the northwest.

[4] The terms " saline " and " fresh " will be used to mean " re tively saline " and " relatively fresh ".

[5] Sigma-t $=\sigma_t=10^8$ (specific gravity -1). A sigma-t surface one of approximately constant potential density in the up 1,000 meters. Isentropic analysis refers to changes of proper on surfaces of equal entropy or sigma-t surfaces.

FIGURE 11. Depth (m.) of the 26.0 sigma-t surface. Dots indicate station positions.

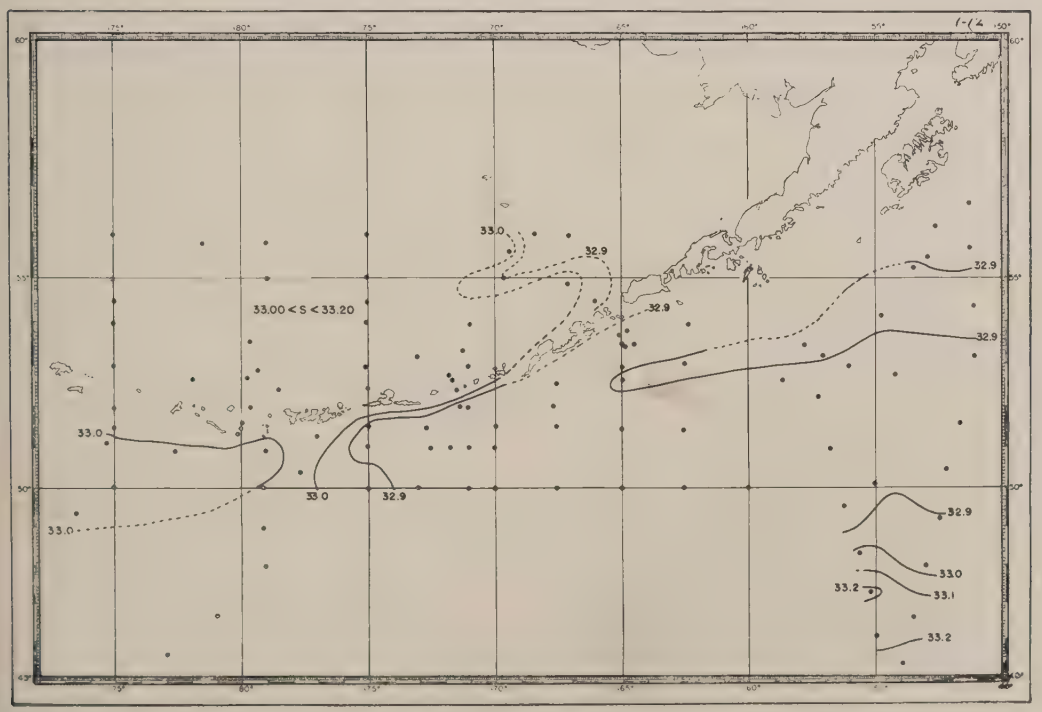
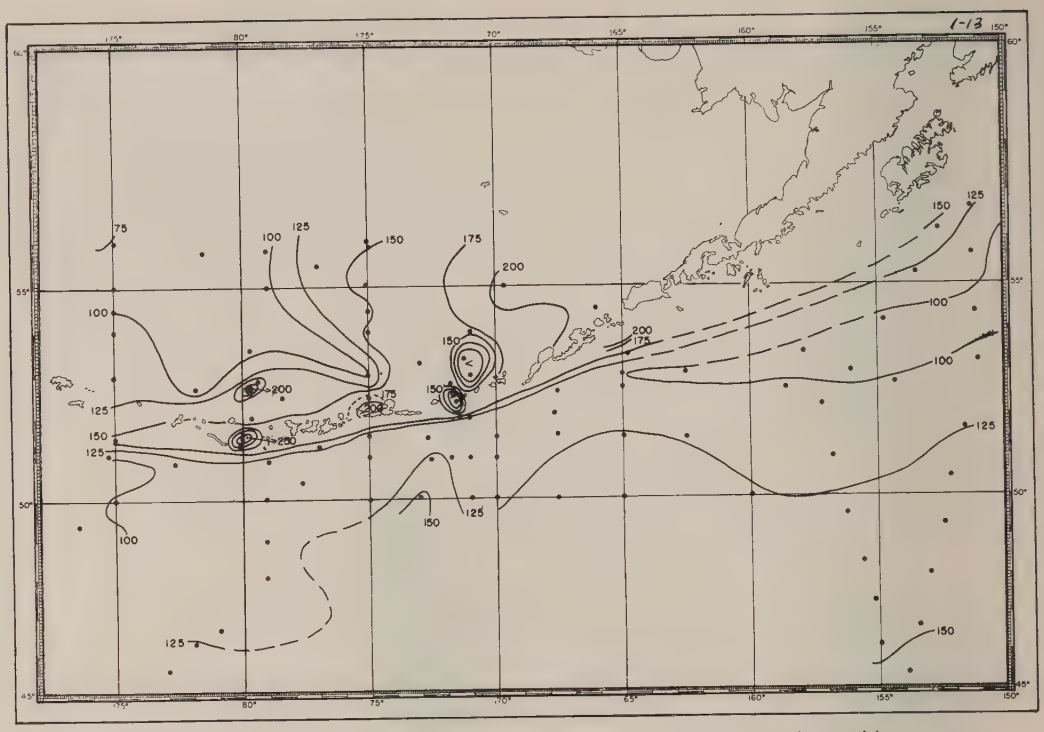


FIGURE 12. Salinity (‰) on the 26.0 sigma-t surface. Dots indicate station positions.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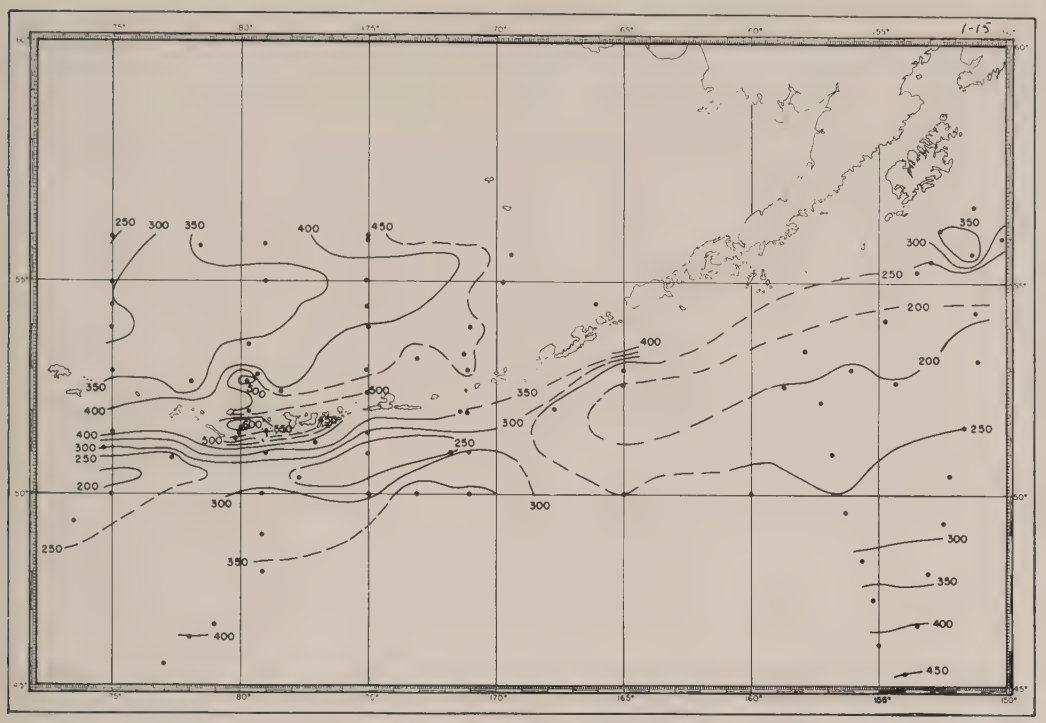


FIGURE 15. Depth (m.) of 27.0 sigma-t surface. Dots indicate station positions.

The salinity distribution on this surface implies a gion of discontinuity at about 51°N., 172°W. This continuity is present also on the 26.0 sigma-t surce, but farther to the west. The depth chart for the .5 sigma-t surface shows an intrusion of water from e south that could account for this discontinuity.

Figure 15 shows the depth of the 27.0 sigma-t surface. ie salinity variation on this surface was too slight permit contouring. Once again the sigma-t lines are continuous along the Aleutian Chain. nly on the 26.0 sigma-t surface was there any indican of movement into Bering Sea. No doubt there more exchange than is here indicated, but the tions in and near the passes are not spaced closely ough to settle this question.

HORIZONTAL DISTRIBUTION OF PROPERTIES

EMPERATURE

Figures 16 to 19 show the temperature distribution 0, 100, 300 and 500 meters, respectively.

Figure 16, surface temperature, is derived from drographic and bathythermograph data. Due to ense vertical mixing in the upper layers, the entire island chain is shown as situated in colder[6] waters than in the Bering Sea or Pacific Ocean. This kind of " upwelling " must be ascribed to tidal mixing rather than to wind stress associated with " classical upwelling ".

The temperature distribution at 100 meters (Fig. 17) differs from the surface distribution in one major respect. Here most of the Aleutian Islands are banded by warm (greater than 5.0°C.) water and the temperature decreases to the north and south. This is the result of the downward curvature of the isotherms at shallow depths near the land masses. At about 50°N., 175°W., there is a break in the less-than-4.0°C. band extending east-west. As mentioned before, there is an indication that this discontinuity has been produced by advection from the south.

Figure 18 shows the temperature distribution at 300 meters. Once again the deeper waters are shown as being warm (greater than 4.0°C.) about the Aleutian Islands. The contour of 4.25°C. is drawn south of the Islands east of 178°W., but it is possible, had there been more data to the north, that this isotherm could have been drawn so as to enclose the Islands.

[6] The terms " cold " and " warm " will be used to mean " relatively cold " and " relatively warm ".

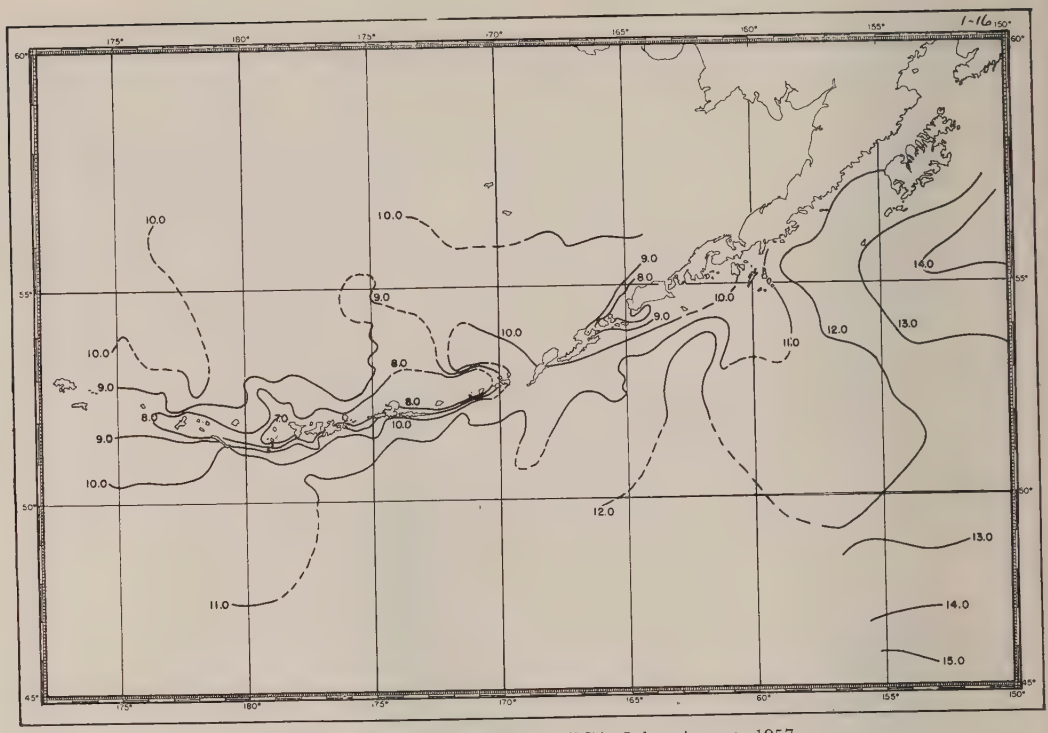


FIGURE 16. Surface temperature (°C.), July—August, 1957.

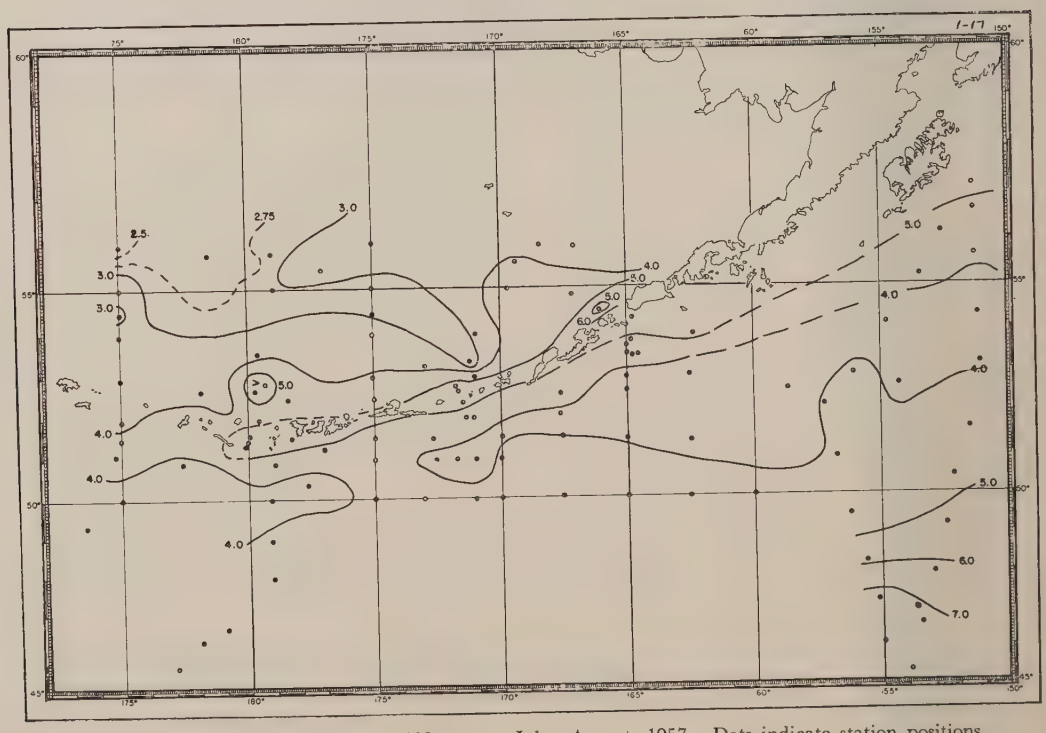


FIGURE 17. Temperature (°C.) at 100 meters, July—August, 1957. Dots indicate station positions.

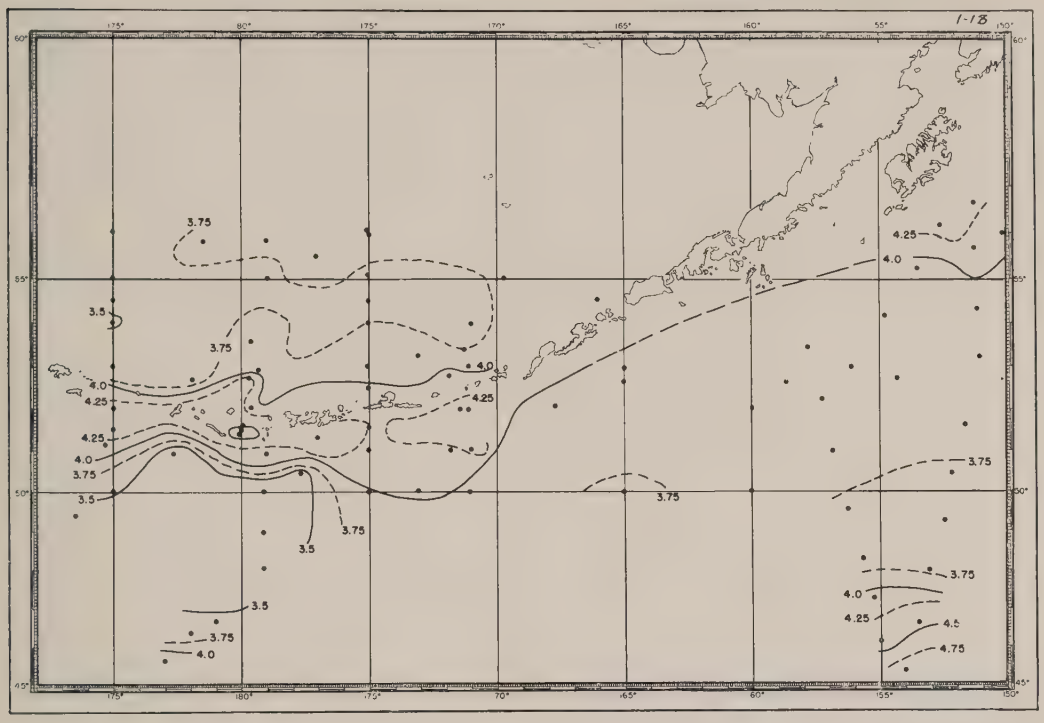


FIGURE 18. Temperature (°C.) at 300 meters, July—August, 1957. Dots indicate station positions.

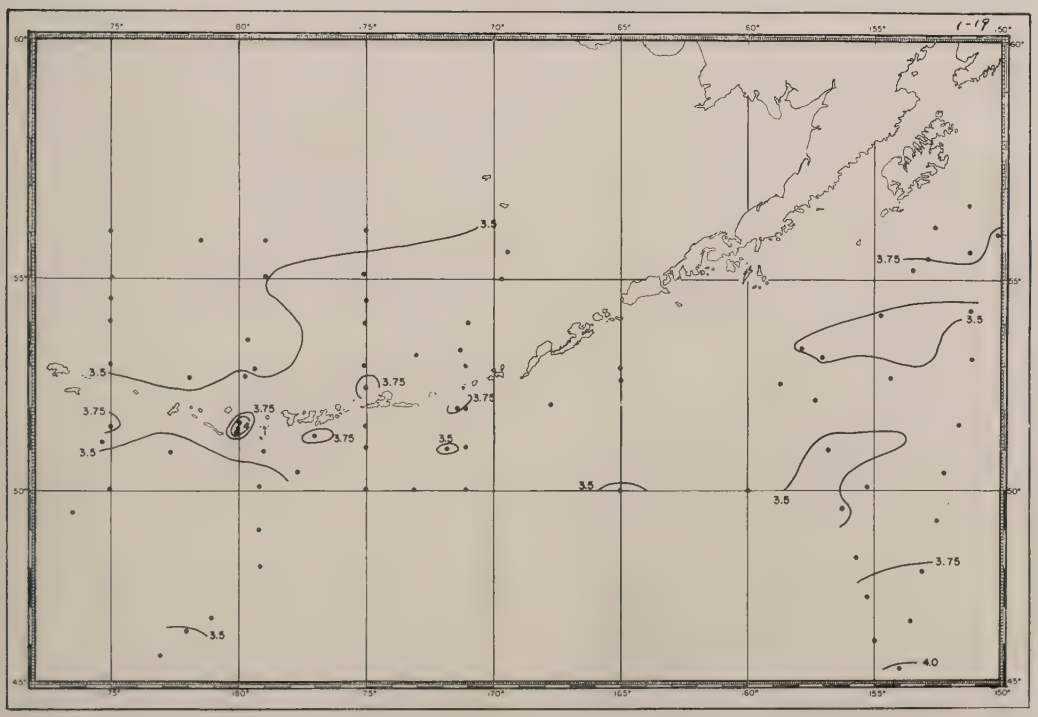


FIGURE 19. Temperature (°C.) at 500 meters, July—August, 1957. Dots indicate station positions.

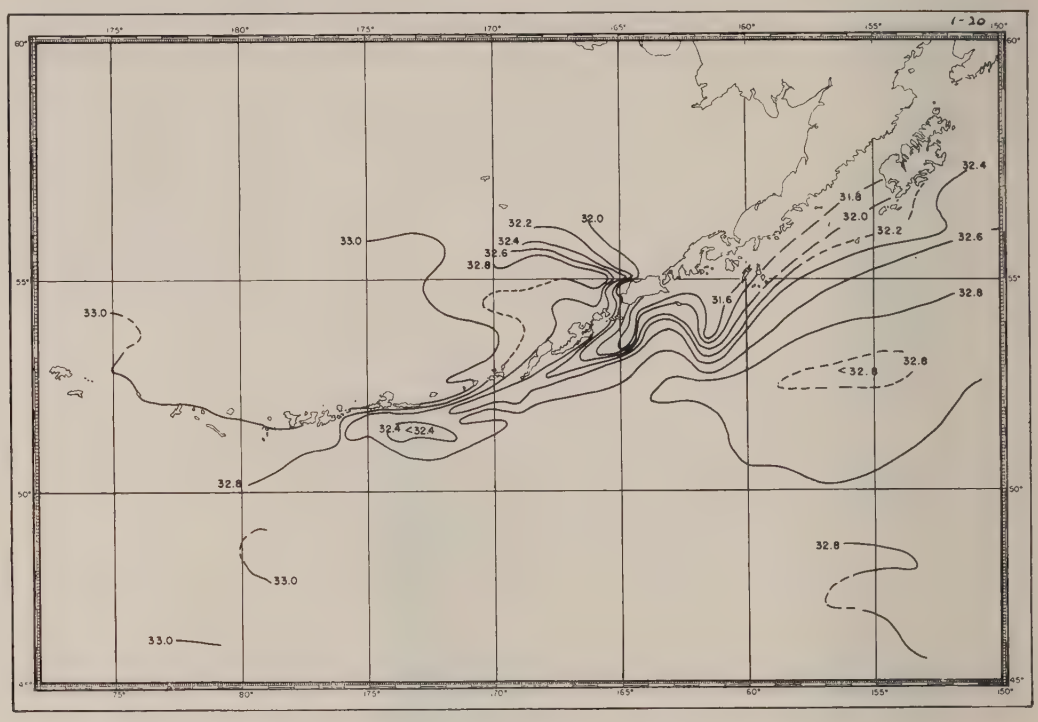


FIGURE 20. Surface salinity (‰), July—August, 1957.

The deepest horizontal section of temperature is at 500 meters (Fig. 19). The Islands are shown as being surrounded in a broad band of 3.5°C. water. There are several cells drawn, based mostly on single observations.

SALINITY

The horizontal distribution of salinity at 0, 10, 100, 300 and 500 meters is shown in Figures 20 to 24, respectively.

The surface salinity chart (Fig. 20), constructed from hydrographic and bathythermograph station data, shows a dilute tongue of water sweeping south of the Islands. This tongue originates from runoff from the Alaska Peninsula and south coast of Alaska. Another tongue, of the same origin, is shown as moving south along 162°W. In the eastern part of the figure there is a salinity ridge of 32.8‰ and a cell of less than 32.8‰ within this ridge. North of Unimak Island there is a salinity gradient directed into Bristol Bay. Here ice-melt and river runoff are responsible for the dilution.

The salinity distribution at 10 meters (Fig. 21) is based on considerably fewer observations than at the surface. The same general features are present, however. The tongues originating near the Alaska Peninsula show fresh water moving to the south the Islands and a protrusion to the southwest. T direction of the secondary (i.e., southwest protrusio tongue has changed and the gradients associated wi both tongues have decreased in magnitude. T Bristol Bay gradient is present at 10 meters but t isohalines terminate on the northern side of the Islan while the surface isohalines were shown as connecti through the passes.

The western Bering Sea salinity distribution essentially the same at 10 meters as at the surfa The 33.0‰ isohaline encloses about the same ar at both depths.

The chart of salinity at 100 meters (Fig. 22) i cludes the 33.3‰ isohaline to show the salinity ran in the western Bering Sea. The dilute tongue sou of Unimak Island is present at this depth, but t secondary tongue has disappeared. A ridge bound by the 33.2‰ isohaline is present as far west as 175°W and two elongated cells (33.4‰) are shown within t ridge. In the eastern part of the ridge, another c (33.4‰) is shown. Dodimead (1958) shows this c extending as far as 55°N., 148°W.

Figure 23 shows salinity at 300 meters. T number of stations is reduced because some casts c not reach this depth. The islands are shown as lyi

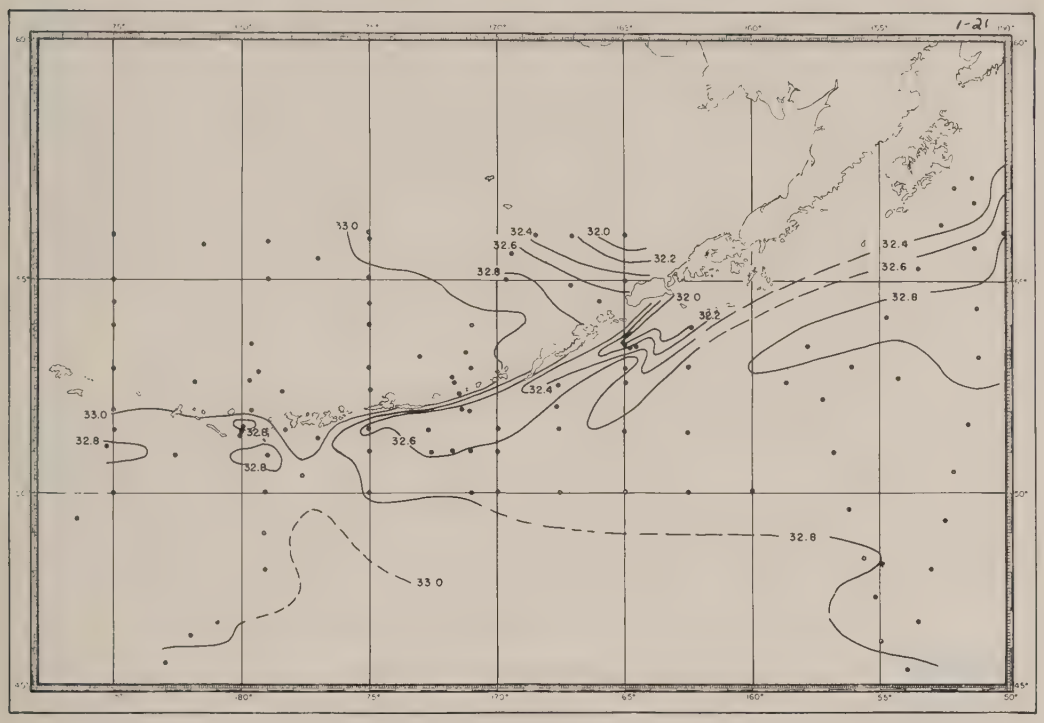


FIGURE 21. Salinity (‰) at 10 meters, July—August, 1957. Dots indicate station positions.

FIGURE 22. Salinity (‰) at 100 meters, July—August, 1957. Dots indicate station positions.

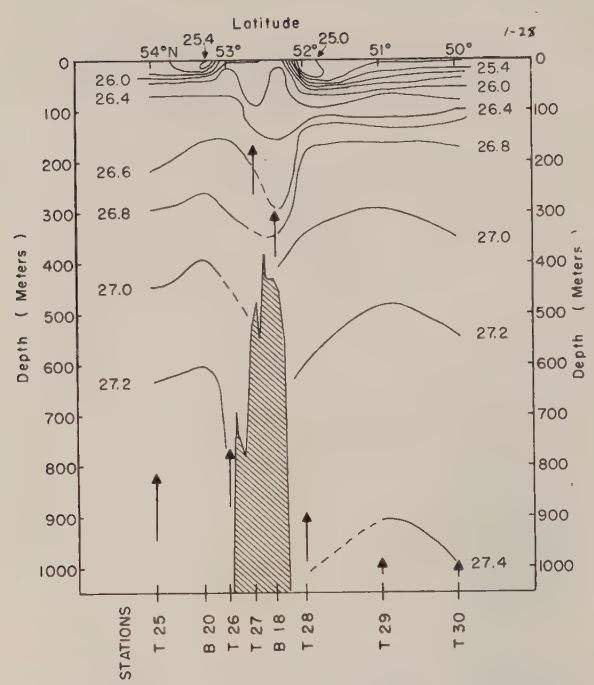


FIGURE 28. Vertical distribution of sigma-t along 171°W. longitude, July—August, 1957. Large arrows indicate depths of Nansen bottle casts not reaching 1,000 meters.

51°30′N., 51°N. and 50°N. are 25.02, 25.11 and 25.19, respectively.

The depth of Amukta Pass is 380 meters (Fig. 28). The 27.0 isopleth is shown as sinking into the ridge on both sides of the pass. At 51°50′N., there is an unstable[7] layer indicated in the upper 30 meters, and in the upper 20 meters at 53°20′N. The dilute tongue in Subarctic waters is again in evidence to about 100 meters. Below 100 meters the Bering Sea isopleths are deeper than in Subarctic water.

The shallow waters of Bristol Bay connect with Subarctic water through Unimak Pass along 165°W. (Fig. 29). Thompson and Van Cleve (1936) have reported recoveries of drift bottles which had presumably drifted into Bristol Bay via Unimak Pass.

SALINITY

Figures 30 to 34 show the vertical sections of salinity corresponding to the sigma-t sections. Since the isopleths of salinity and sigma-t take nearly the same course only small details would be included in a

[7] The expression for stability in the upper 100 meters is given by $E=(10^{-3})\, d\sigma_t/dz$, where E is stability and z is depth. A negative E means instability.

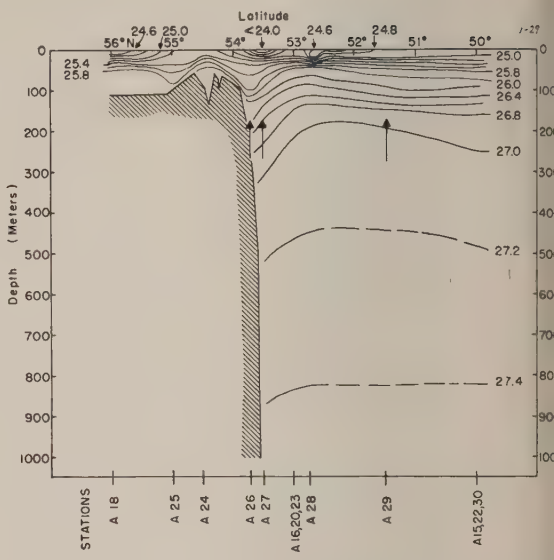


FIGURE 29. Vertical distribution of sigma-t along 165°W longitude, July—August, 1957. Large arrows indicate depths of Nansen bottle casts not reaching 1,000 meters (south of 54°N.).

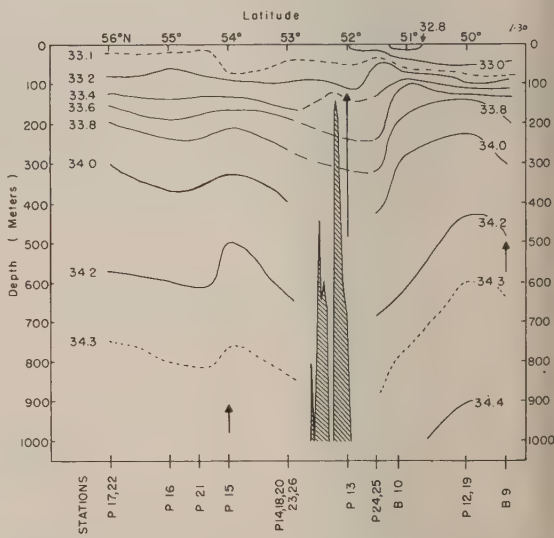
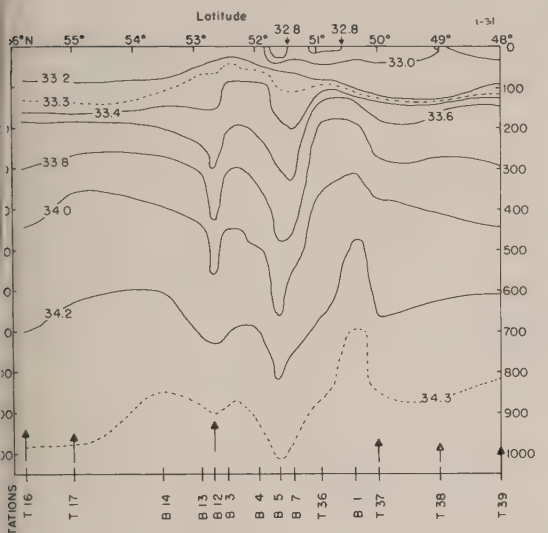


FIGURE 30. Vertical distribution of salinity (‰) along 175°W longitude, July—August, 1957. Large arrows indicate depths of Nansen bottle casts not reaching 1,000 meters.

separate discussion of the salinity sections.

In the upper 100 meters, the isohalines bend toward the sea surface in the vicinity of the Islands. Below 100 meters the isohalines deepen toward the submerged land masses. The isohalines in the Bering Sea are deeper than their counterparts in the Pacific Ocean, the difference in depth increasing toward the ea



URE 31. Vertical distribution of salinity (‰) along 179°W. ongitude, July—August, 1957. Large arrows indicate depth f Nansen bottle casts not reaching 1,000 meters.

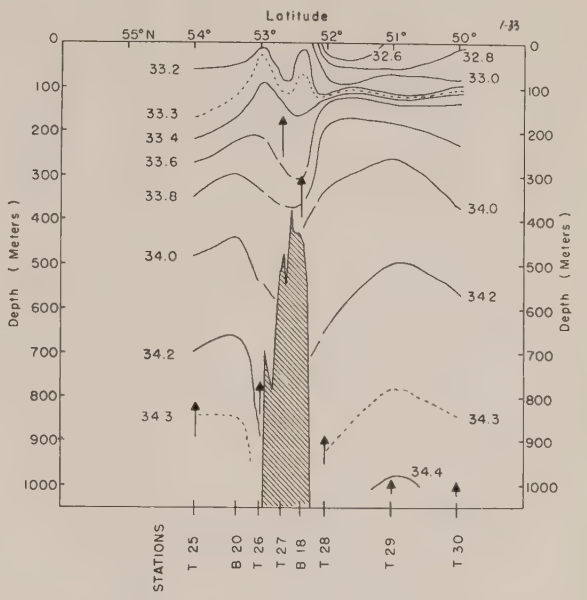
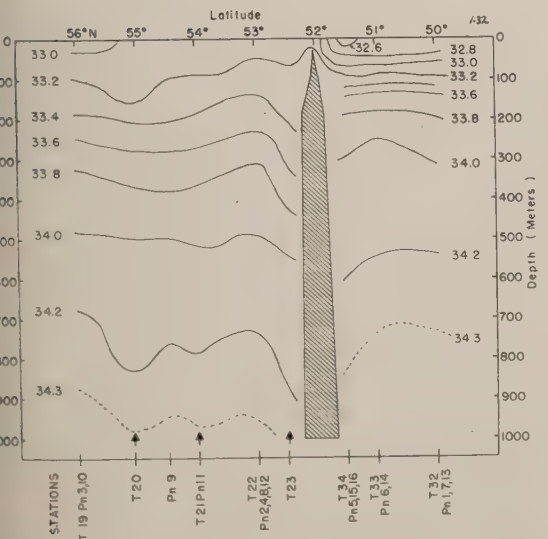


FIGURE 33. Vertical distribution of salinity (‰) along 171°W. longitude, July—August, 1957. Large arrows indicate depth of Nansen bottle casts not reaching 1,000 meters.



URE 32. Vertical distribution of salinity (‰) along 175°W. ongitude, July—August, 1957. Large arrows indicate depth of Nansen bottle casts not reaching 1,000 meters.

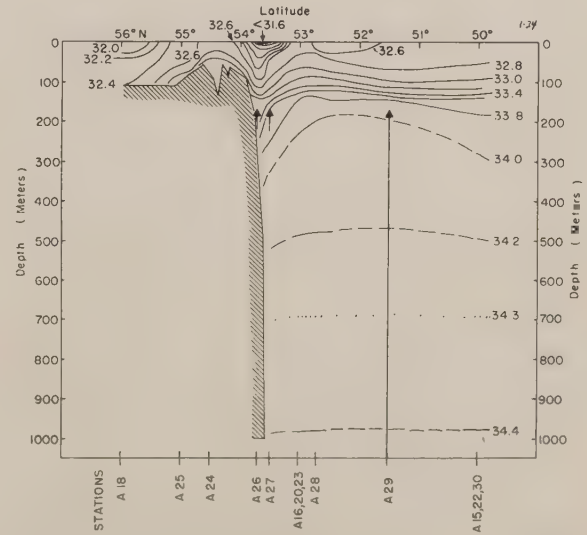


FIGURE 34. Vertical distribution of salinity (‰) along 165°W. longitude, July—August, 1957. Large arrows indicate depth of Nansen bottle casts not reaching 1,000 meters.

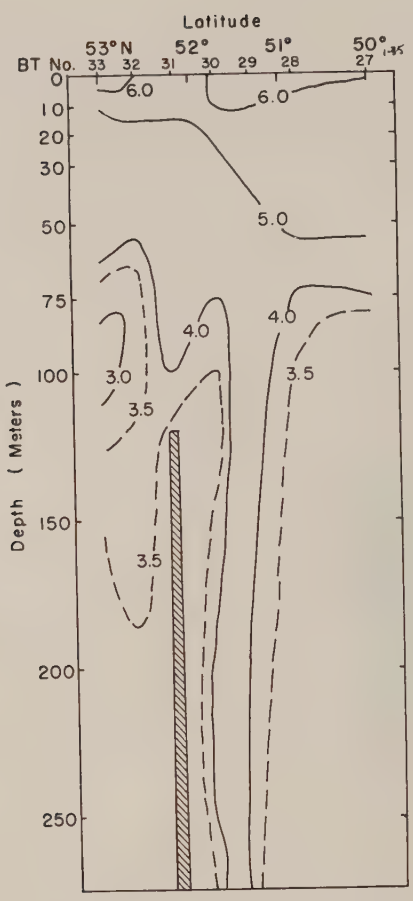


FIGURE 35. Bathythermograph (m., °C.) section along 175°E. longitude, MV *Pioneer*, June 12-14, 1957. BT 27—33.

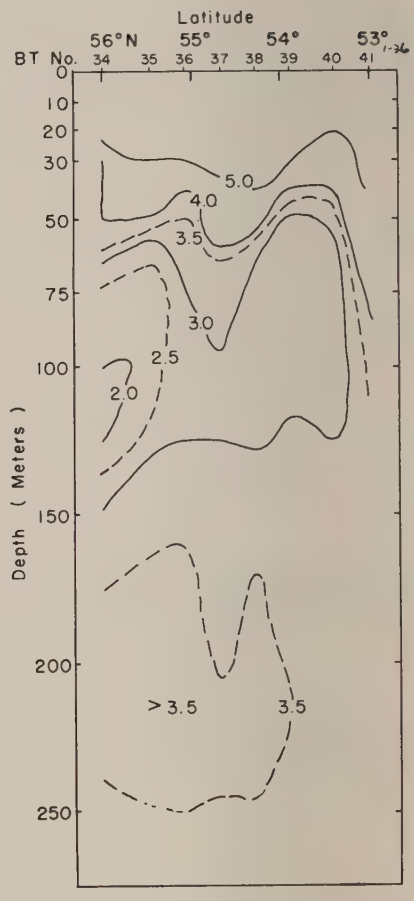


FIGURE 36. Bathythermograph (m., °C.) section a.ong 17 longitude, MV *Pioneer*, June 17-20, 1957. BT 34—41.

The 33.2‰ isohaline is shown as a continuous line along all longitudes except 165°W., where the 32.8‰ isohaline extends only into Unimak Pass.

TEMPERATURE

Bathythermograph (BT)[8] sections are shown in Figures 35 to 55. A detailed discussion of the individual BT sections will not be given here; rather, the main features will be outlined.

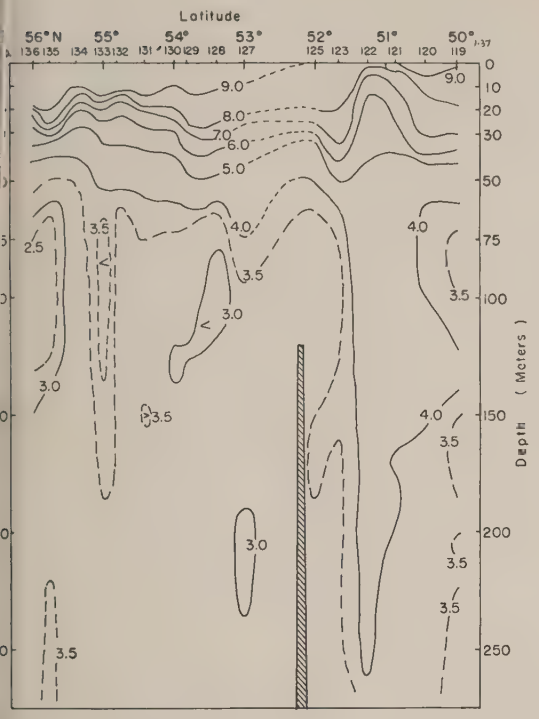
Stommel (1958) has pointed out that when temperature is not a monotonic function of depth, the interpretation involved in drawing isotherms through maxima and minima can be ambiguous. This is true where temperature inversions occur in isolated cases. It is a characteristic of Subpolar waters that a temperature minimum is found at depths ranging from 50 to 150 meters, and there is no ambiguity infe in this widespread phenomenon.

Uda (1935) has applied the name " dichotherm to the inversion layer. The temperature inver below the minimum he has called " mesothermal

In the BT sections, the dichothermal layer is bou ed by the 3.0°C.–4.0°C. isotherms. The minim temperature in the layer ranges from about 1.5°C 3.8°C. Along 175°W., the dichothermal structu shown as reaching its southern limit at about 50°3 (Fig. 41). Associated with the dichothermal st ture is a halocline, through which stability is m tained in the dichothermal layer.

Figures 35–40 show thermocline development a 175°E. In Figures 35–36, no thermocline is pres but by July 22–27 (Fig. 37), the thermocline is sh at about 10–20 meters. By late July (Fig. 38), thermocline depth is 20–25 meters. In Figure 39,

[8] The accuracy of the BT is about ±3 meters (275-meter cast) and about ±0.2°C.



RE 37. Bathythermograph (m., °C.) section along 175°E.
ngitude, MV *Pioneer*, July 22-27, 1957. BT 119—136.

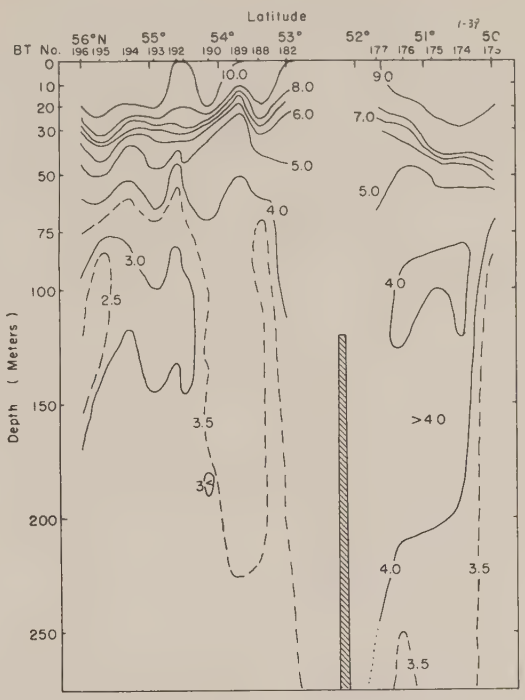
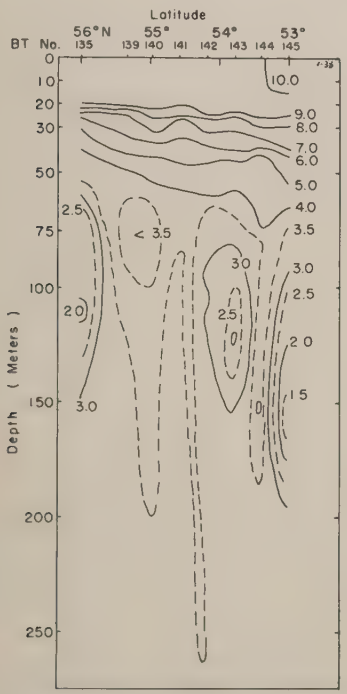


FIGURE 39. Bathythermograph (m., °C.) section along 175°E.
longitude, MV *Pioneer*, August 9-14, 1957. BT 173—196.



RE 38. Bathythermograph (m., °C.) section along 175°E.
ngitude, MV *Pioneer*, July 28-29, 1957. BT 138—145.

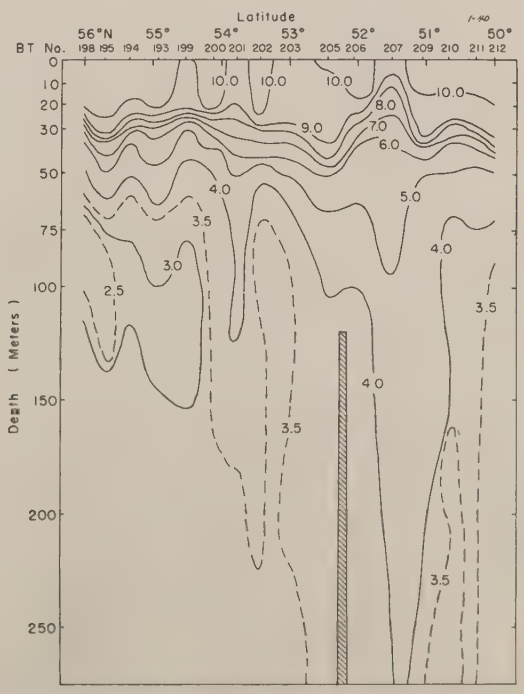


FIGURE 40. Bathythermograph (m., °C.) section along 175°E.
longitude, MV *Pioneer*, August 14-20, 1957. BT 193—212.

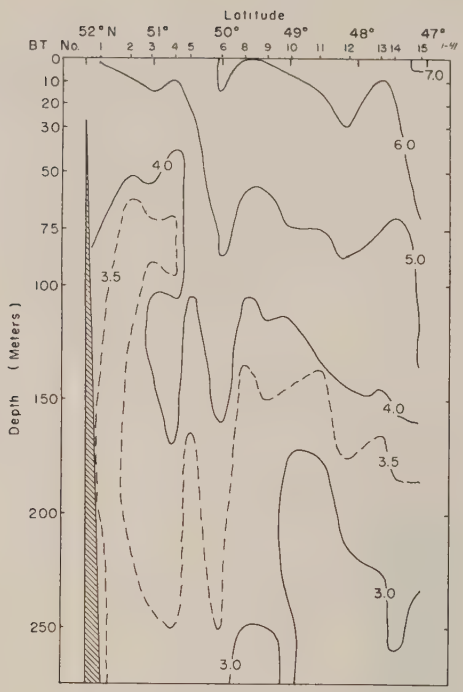


FIGURE 41. Bathythermograph (m., °C.) section along 175°W. longitude, MV *Attu*, May 27—June 1, 1957. BT 1—15.

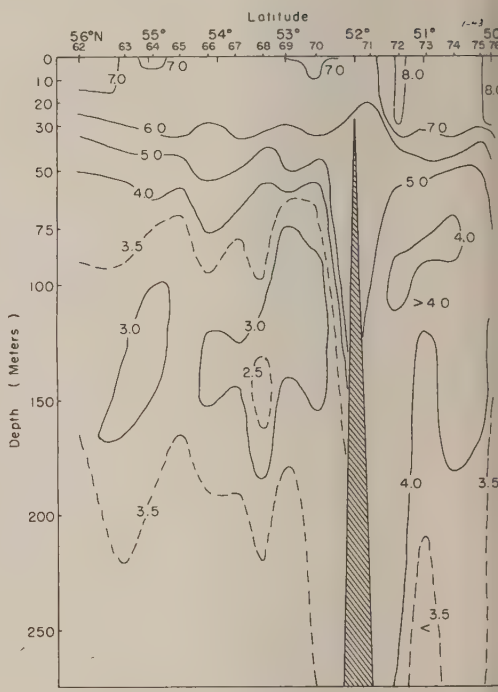


FIGURE 43. Bathythermograph (m., °C.) section along 1 longitude, MV *Pioneer*, June 30—July 5, 1957. BT 62

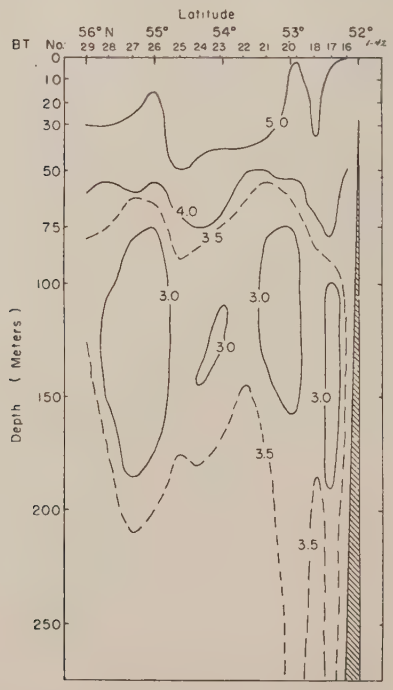


FIGURE 42. Bathythermograph (m., °C.) section along 175°W. longitude, MV *Attu*, June 7-8 (BT 16—20), June 14-15 (BT 21—29), 1957.

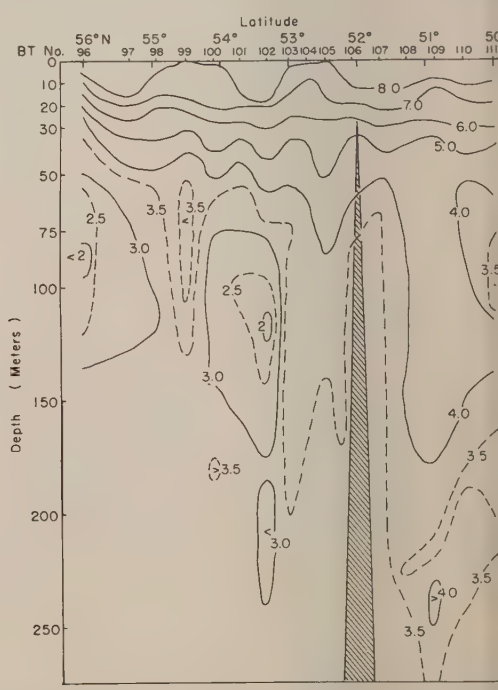
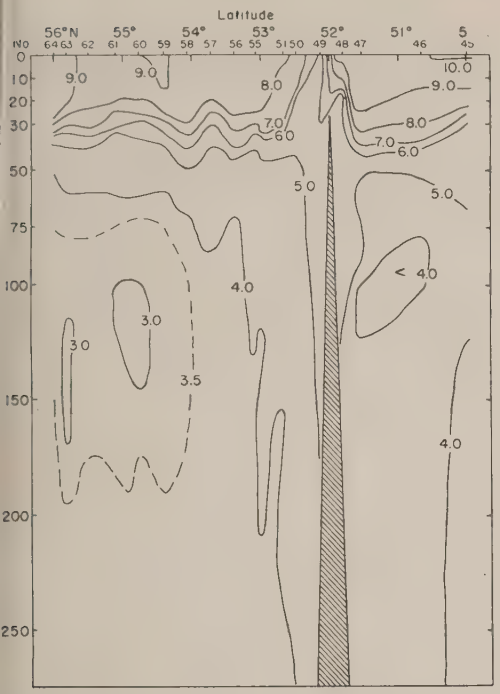


FIGURE 44. Bathythermograph (m., °C.) section along 1 longitude, MV *Pioneer*, July 16-20, 1957. BT 96—11



RE 45. Bathythermograph (m., °C.) section along 175°W. gitude, MV *Paragon*, July 22-27, 1957. BT 45—64.

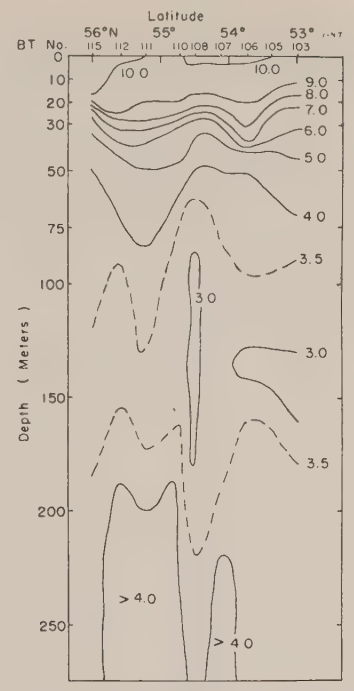
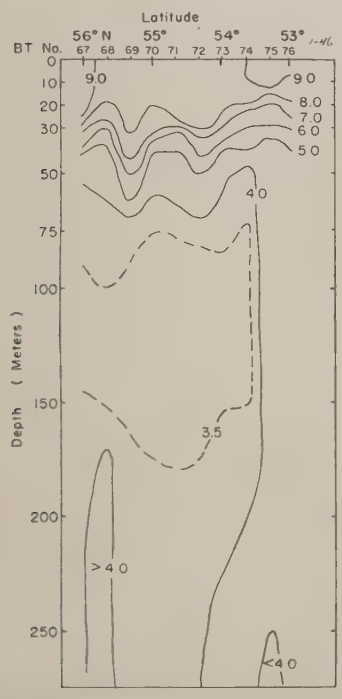


FIGURE 47. Bathythermograph (m., °C.) section along 175°W. longitude, MV *Paragon*, August 12-15, 1957. BT 103—115.



RE 46. Bathythermograph (m., °C.) section along 175°W. ngitude, MV *Paragon*, July 28-30, 1957. BT 67—76.

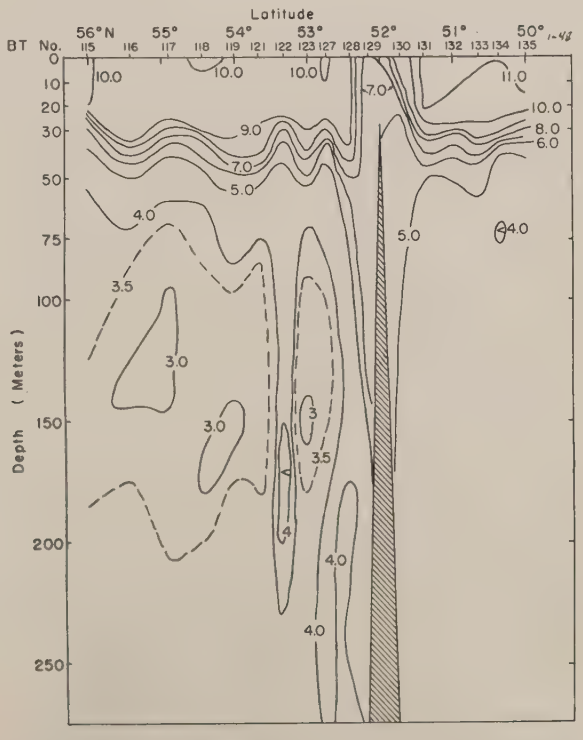


FIGURE 48. Bathythermograph (m., °C.) section along 175°W. longitude, MV *Paragon*, August 15-20, 1957. BT 115—135.

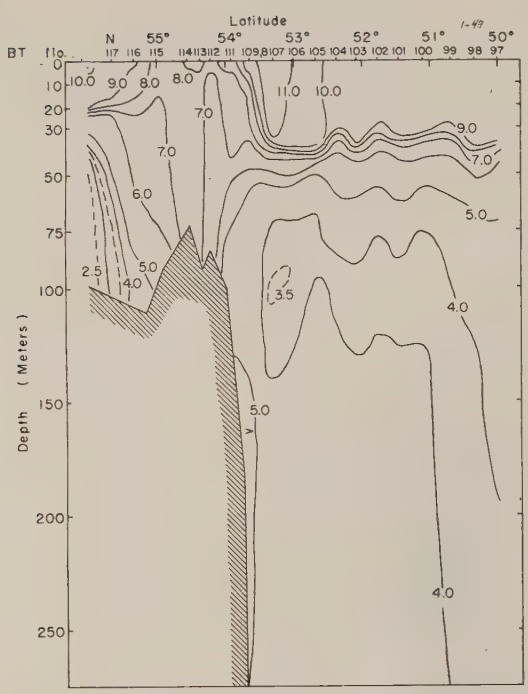


FIGURE 49. Bathythermograph (m., °C.) section along 165°W. longitude, MV *Attu*, July 22-27, 1957. BT 97—118.

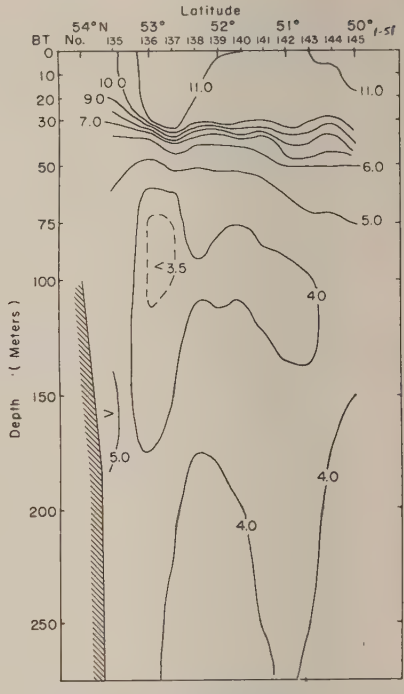


FIGURE 51. Bathythermograph (m., °C.) section along 16 longitude, MV *Attu*, August 7-9, 1957. BT 135—145.

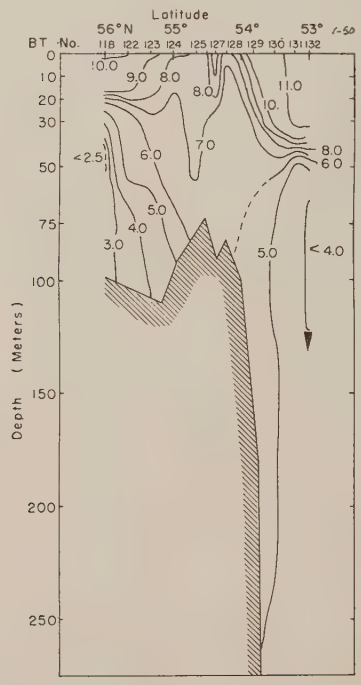


FIGURE 50. Bathythermograph (m., °C.) section along 165°W. longitude, MV *Attu*, July 27-30, 1957. BT 118—132.

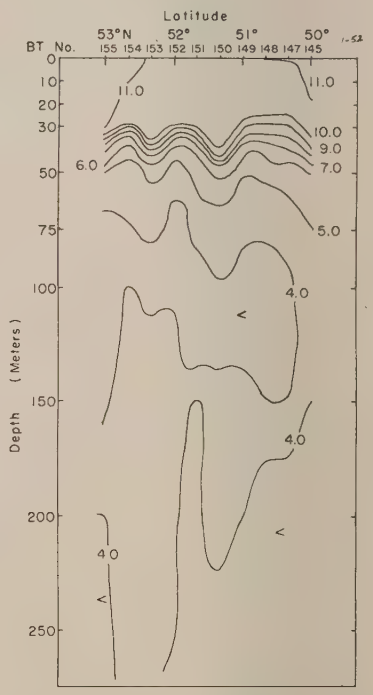
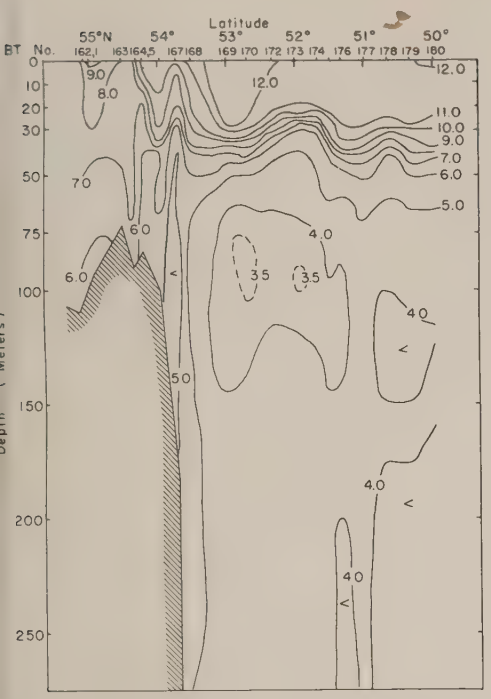
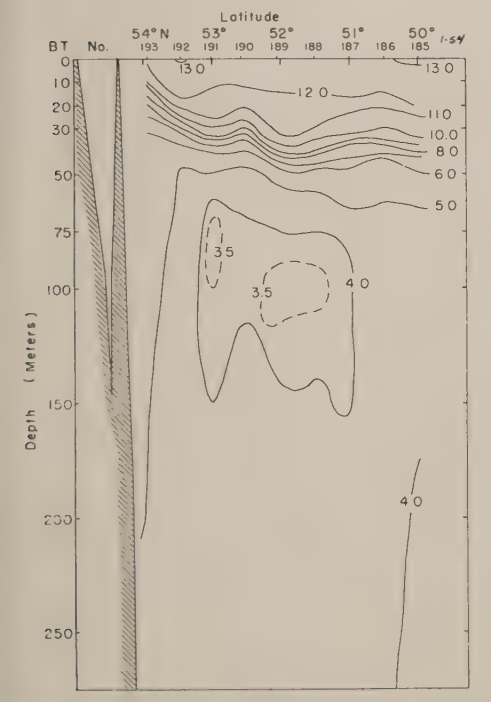


FIGURE 52. Bathythermograph (m., °C.) section along 16 longitude, MV *Attu*, August 9-15, 1957. BT 145—155



URE 53. Bathythermograph (m., °C.) section along 165°W. ngitude, MV *Attu*, August 15-20, 1957. BT 161—180.



URE 54. Bathythermograph (m., °C.) section along 162°W. ngitude, MV *Attu*, August 22-23, 1957. BT 185—193.

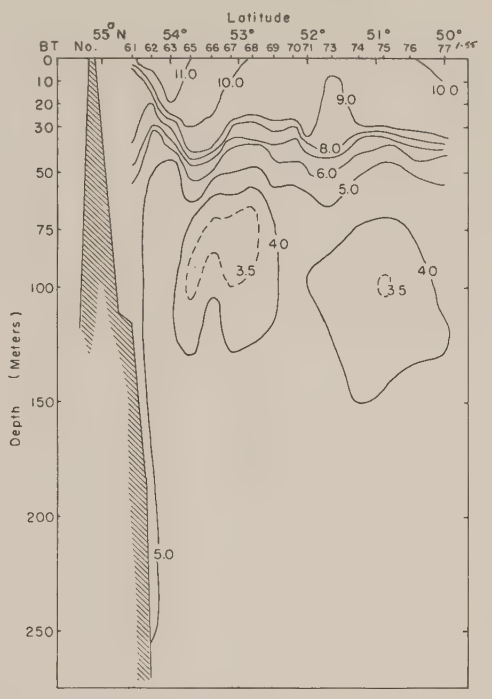


Figure 55. Bathythermograph (m., °C.) section along 160°W. longitude, MV *Attu*, July 14-19, 1957. BT 61—77.

thermocline is shown as approaching the surface in the vicinity of the pass (lat. 52°N. to 53°N.), but in Figure 40 this feature is not present.

Figures 41–48 show the development of the thermocline along 175°W. In Figures 41–42, the thermocline is as yet unformed, but Figure 43 (June 30–July 5) shows that the temperature gradient between 30–60 meters has increased. In Figure 44 (July 16–20), the thermocline is well developed, and by the third week in July and through August (Fig. 45–48) reaches its maximum gradient in temperature across the thermocline layer and its maximum depth (30–35 meters). In Figures 45 and 48, the isothermal layer over Atka Pass indicates that tidal mixing is effective throughout the water column.

Figures 49–53 show the temperature distribution along 165°W. In Figure 49, the warm (greater than 11.0°C.) dilute tongue is clearly in evidence. Warm (greater than 5.0°C.) water is shown as lying between 120–175 meters next to the submerged land mass. The effect of tidal mixing is present between 54°N.–55°N., and cold (less than 2.5°C.) water of Bristol Bay origin is shown between 55°30′N.–56°N.

Single sections along 162° 30′W. and 160°W. are shown in Figures 54 and 55, respectively. In Figure

54 (August 22–23), the warm water of Gulf of Alaska origin is not present as a well-defined wedge, but the 12°C. isotherm is at depths of about 15 meters. Figure 55 (July 14–19) shows the core (greater than 10°C.) as lying between 53°N.–54°30′N. BT's 61–62 indicate warm (5°C.) water at depths of over 200 meters near the Shumagin Islands.

The annual cycle of temperature (Fig. 3) indicates that in February the surface waters down to 300 feet (91 meters) are isothermal, about 38.1°F. (3.4°C.). The 400-foot (122-meter) curve shows that water at this depth is about 39.1°F. (3.9°C.).

The 3.4°C. surface layer temperature is cold enough to account for most of the dichothermal layer in the Pacific Ocean; that is, presuming overturn of these waters. This process of overturn, however, is probably continuous once cooling begins.

Advection of cold Oyashio water contributes to the dichothermal structure, but overturn is the main source in the Pacific Ocean and Bering Sea, as discussed below.

Sverdrup *et al.* (1942, p. 732) suggest that in the Subarctic region the temperature minimum represents the depth of winter convection currents. Doe (1955) and Dodimead (1958) have also related the dichothermal layer to winter cooling and overturn. Based on data from weather station PAPA (50°N., 145°W.), Dodimead found that surface cooling in February, 1957, was less than in the previous winter. He found that in the Gulf of Alaska region the minimum temperatures were about 0.5°C. less in August, 1956, than in 1957. Bennett (1959) has presented charts of the depth of minimum temperature for August, 1955, in the Gulf of Alaska. The isotherm patterns for the temperature minimum structure are closely similar to the surface geostrophic current pattern for the same period.

Graphical subtraction of BT temperature sections (not shown) reveals that, with the procession of summer, cold water advection occurs in both the Pacific Ocean and Bering Sea dichothermal structure.

SUMMARY

It has been shown by others that the Subpolar region is one of net dilution. Dilution of the surface waters by runoff continues past the time period included in this report. Surface temperature increased into late August.

It is shown that the geostrophic assumption is not a close approximation near the Islands since the pressure gradient is not vanishing at depth. East of Amchitka Pass, the steric level north of the Aleu Islands is greater than on the Pacific Ocean s Major water exchange is through Amchitka Pass between Attu and Kiska Islands, with the direc of flow being into Bering Sea.

In the upper 50 and 100 meters, the isotherms isohalines, respectively, approach the surface near Islands. Below these depths they bend down. surface temperature chart pictures the Islands as l in cold water, the result of tidal mixing in the pa and around the Islands. Below 100 meters the Isla are shown as lying in warm waters.

The dichothermal structure is present in the Be Sea and Pacific Ocean. The temperatures in dichothermal layer can be accounted for by overt of winter-cooled surface water. Advection also tributes to the cold waters of the inversion layer. thermocline begins to form in late June, and by third week in July is well developed.

LITERATURE CITED

Aron, William. 1959. Midwater trawling studies in the N Pacific. *Limnology and Oceanography*, 4(4) : 409–418.

Barnes, Clifford A., and Thomas G. Thompson. 1938. P cal and chemical investigations in Bering Sea and por of the North Pacific Ocean. *University of Washington* (Sea *Publications in Oceanography*, 3(2) : 35–79, and *Appendix :* 1–1

Bennett, E. B. 1959. Some oceanographic features of northeast Pacific Ocean during August, 1955. *Journal Fis Research Board of Canada*, 16(5) : 565–633.

Dodimead, A. J. 1958. Report on oceanographic investiga in the northeast Pacific Ocean during August, 1956, Febr 1957 and August, 1957. *Fisheries Research Board of Ca Manuscript Report Series (Oceanographic and Limnological)*, No 14 pp., 35 figs.

Doe, L. A. E. 1955. Offshore waters of the Canadian Pa Coast. *Journal Fisheries Research Board of Canada*, 12(1) : 1-

Favorite, Felix, and Cuthbert M. Love. 1957. North Pa Ocean and Gulf of Alaska physical and chemical data, sun and fall 1955. *University of Washington* (Seattle), *Departm Oceanography, Special Report*, No. 28, 88 pp., 1 fig.

Favorite, Felix, and Glenn Pedersen. 1959a. North Pa and Bering Sea oceanography, 1957. *U.S. Fish and Wi Service, Special Scientific Report—Fisheries*, No. 292, 106 pp.

Favorite, Felix, and Glenn Pedersen. 1959b. North Pa and Bering Sea oceanography, 1958. *U.S. Fish and Wi Service, Special Scientific Report—Fisheries*, No. 312, 230 pp.

Fleming, Richard H. 1955. Review of the oceanograph the northern Pacific. *Bulletin International North Pacific Fis Commission* (Vancouver, Canada), No. 2, 43 pp.

Fleming, Richard H., and Staff. 1958. Physical and chem data, North Pacific Ocean. Brown Bear Cruise 176, September, 1957. *University of Washington* (Seattle), *Depar of Oceanography, Special Report*, No. 29, 15 pp. (91) p. table

Goodman, Joe R., John H. Lincoln, Thomas G. Thompson Frederick A. Zeusler. 1942. Physical and chemical in

.ons: Bering Sea, Bering Strait, Chukchi Sea during the ımers of 1937 and 1938. *University of Washington* (Seattle), *lications in Oceanography*, 3(4): 105–169, and *Appendix:* 1–117.

RD, JAMES F. 1959. Currents in southeastern Bering Sea l possible effects upon king crab larvae. *U.S. Fish and ldlife Service, Special Scientific Report—Fisheries*, No. 293, 11 pp.

AIDO REGIONAL FISHERIES RESEARCH LABORATORY. 1958. preliminary data of physical oceanography obtained research sel "Tenyo-maru" in the Bering Sea and the Aleutian ters (July-August, 1957). Hokkaido Regional Fisheries search Laboratory (Yoichi, Japan), 30 pp., 1 fig. (processed).

RNATIONAL NORTH PACIFIC FISHERIES COMMISSION. 1959. port on the investigations by the United States for the ernational North Pacific Fisheries Commission—1958. *In:* ernational North Pacific Fisheries Commission (Vancouver, nada), Annual Report for the year 1958, p. 74–119.

ıs, WOODROW C. 1951. The energy exchange between sea l atmosphere and some of its consequences. *Bulletin Scripps itution of Oceanography*, 6(2): 27–122.

NO, KIYOMITSU. 1958. Oceanographic structure of the ing Sea and the Aleutian waters. Part I. Based on the anographic observations by R. V. "Tenyo-maru" of 1957. letin *Hokkaido Regional Fisheries Research Laboratory*, 19: 1–9.

, CUTHBERT M. 1957. Physical and chemical data—Gulf Alaska spring and summer 1956 and spring 1957. *University Washington* (Seattle), *Department of Oceanography, Technical ort*, No. 56, 90 pp.

, CUTHBERT M. 1959. Physical and chemical data, North cific Ocean, Gulf of Alaska and Bering Sea summer of 1956. *versity of Washington* (Seattle), *Department of Oceanography, cial Report*, No. 31, 13 pp., 216 p. tables, 2 figs.

rGOMERY, R. B. 1938. Circulation in upper layers of southern North Atlantic deduced with use of isentropic analysis. *Papers in Physical Oceanography and Meteorology*, 6(2): 55 pp.

PACIFIC OCEANOGRAPHIC GROUP. 1957. Physical, chemical and plankton data record, North Pacific survey, July 23 to August 30, 1957. *Fisheries Research Board of Canada, Manuscript Report Series (Oceanographic and Limnological)*, No. 4, 103 pp.

PATTULLO, JUNE, W. MUNK, R. REVELLE AND ELIZABETH STRONG. 1955. The seasonal oscillation in sea level. *Journal of Marine Research*, 14(1): 88–156, 1 chart.

ROBINSON, MARGARET K. 1957. Sea temperature in the Gulf of Alaska and in the northeast Pacific Ocean, 1941–1952. *Bulletin Scripps Institution of Oceanography*, 7(1): 1–98.

STOMMEL, HENRY. 1958. The Gulf Stream. University of California Press (Berkeley), 202 pp.

SVERDRUP, H. U., MARTIN W. JOHNSON AND RICHARD H. FLEMING. 1942. The oceans: their physics, chemistry and general biology. Prentice-Hall (New York), 1087 pp.

THOMPSON, WILLIAM F., AND RICHARD VAN CLEVE. 1936. Life history of the Pacific halibut. (2) Distribution and early life history. *Report of the International Fisheries Commission* (Seattle, Washington), No. 9, 184 pp.

TULLY, J. P., AND F. G. BARBER. 1960. An estuarine analogy in the Sub-Arctic Pacific Ocean. *Journal Fisheries Research Board of Canada*, 17(1): 91–112.

UDA, M. 1935. On the distribution, formation, and movement of the dichotherm water in the northeastern sea region adjacent to Japan. *Umi to Sora*, 15(12).

U. S. COAST AND GEODETIC SURVEY. 1955. United States Coast Pilot 9: Alaska, Cape Spencer to Arctic Ocean. Sixth (1954) Edition, Government Printing Office (Washington, D.C.), 673 pp.

FACTORS ASSOCIATED WITH LOW DISSOLVED OXYGEN CONCENTRATIONS IN LAKE ERIE. J. F. Carr, A. M. Beeton and H. Allen, U. S. Bureau of Commercial Fisheries, Ann Arbor.

Very low dissolved oxygen concentrations have been observed in the bottom waters of the central basin of Lake Erie each year since first detected in 1957. Synoptic surveys of the lake in 1959 and 1960 indicated that as much as 1,600 square miles of the central basin may have dissolved oxygen concentrations of 1 part per million or less. Noticeable decrease in the dissolved oxygen content of the hypolimnetic waters occurs about the second week of July and continues, at low levels, until around the end of September. The lowest oxygen content only occurs in areas where pronounced thermal stratification persists.

Laboratory and field measurements were made of the oxygen demand of the water and sediments, and of the organic content of the sediments. A very rapid uptake of dissolved oxygen occurs when a small amount of sediment is mixed with oxygenated water. This immediate oxygen demand is probably chemical whereas a continued gradual uptake of oxygen is probably biological. The oxygen demand of the hypolimnetic waters was not great enough to account for the low dissolved oxygen concentrations observed in the environment. The high immediate oxygen demand sediments have the greatest organic content. However, the oxygen uptake over centrifuged mud cores were not necessarily higher in samples with high organic content nor in samples having a high immediate demand.

OXYGEN DEFICIT RATES FOR THE CENTRAL BASIN OF LAKE ERIE. Nelson A. Thomas, U. S. Public Health Service, Cincinnati.

Changes in water chemistry of the Central Basin of Lake Erie were determined for the period of 1928 to 1960 by the use of oxygen deficit rates. Photosynthetic rates and carbon dioxide production data for the Central Basin of Lake Erie are not available. Total amounts of oxygen in the hypolimnion of the Central Basin of Lake Erie were determined for two days that were at least one month apart. Oxygen values for 1928 gave an oxygen deficit rate as .0065 mgm/cm^2/day. Oxygen deficit rates calculated for 1959 and 1960 were 0.03 and 0.037 mgm/cm^2/day respectively. Productivity, as measured by oxygen deficit, has increased 5.7 times from 1928 to 1960. The maximum oxygen deficit rate for the stagnation period of the Central Basin must not exceed 0.04 mgm/cm^2/day if aerobic conditions are to be maintained at all times.

Oxygen data for the summer of 1960 indicate that oxygen in the hypolimnion was utilized during the entire stagnation period. By late August 1960, 70 percent of the total oxygen had been consumed in the hypolimnion.

Reprint from Proceedings of Sixth Conference on Great Lakes Research, 1963.

CHANGES IN THE BOTTOM FAUNA OF LAKE ERIE, WEST OF THE ISLANDS, 1930-1961. J. F. Carr and J. K. Hiltunen, U. S. Bureau of Commercial Fisheries, Ann Arbor.

The sampling of 40 stations in the extreme western end of Lake Erie was undertaken to determine the changes in the species composition, distribution, and abundance of benthic organisms since a similar survey of this nature in 1930. Comparison of the 1961 data with those for 1930 show that few of the formerly abundant mayfly nymphs now inhabit the western basin, but there has been a great increase in tubificid worms and midge larvae. Stillman Wright (1955), author of the 1930 survey, used the numbers of tubificid worms per square meter as being indicative of the degree of pollution; more than 5000 worms per square meter was accepted as indicating heavy pollution. In 1930, heavy pollution was confined to two small areas, off the River Raisin and inside Maumee Bay. In 1961, the area of heavy pollution now includes an extensive area around the mouth of the Detroit River and most of the waters extending 2 or 3 miles out along the shore between Detroit and Maumee Bay.

Reprint from Proceedings of Sixth Conference on Great Lakes Research, 1963.

6.

Size Selection of Fish by Otter Trawls
Results of Recent Experiments in the Northwest Atlantic

by

JOHN R. CLARK[1]

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A. INTRODUCTION TO SELECTION EXPERIMENTS

Introduction

Studies of optimum yields for Northwest Atlantic groundfish species have been greatly intensified by the United States since the establishment of the International Commission for the Northwest Atlantic Fisheries. Controlling the fishing mortality of the early ages of fish has come to be an accepted method of providing optimum yields for species taken by otter trawl. This control is accomplished by adjusting the ize of mesh in the nets to permit escapement of fish below a chosen size.

An extensive series of experiments with various species of fish and types of nets was carried out during the years 1952 to 1956 by the Woods Hole Laboratory of the U. S. Fish and Wildlife Service to provide adequate bases for the regulation of mesh sizes (Table 1). The results of these experiments are presented in the following series of papers. It is the purpose of this report to describe methods and equipment used and to present other general background material.

TABLE 1. Summary of Mesh Selection Experiments, 1952-1956

Cruise	No.	Date	Primary Purpose	Other Purposes
Michigan	1	June 4-12 1952	Selection of haddock by manila codends	Validity of covered codend method
Michigan	2	June 15-22 1952	do.	do.
Wisconsin		Oct. 15-19 1952	do.	do.
Albatross III	49	May 15-20 1953	do.	Escapement through under side of codend. Effect of tow duration Escapement through top belly
Albatross III	51	June 8-17 1953	Validity of covered codend method for haddock	Selection of manila codends Escapement through various parts of codend. Escapement through top belly
Albatross III	52	July 20-29 1953	do.	Selection of manila codends Escapement through top belly
Priscilla V	1-5	Sept. 13-Nov. 2 1954	Selection of silver hake by manila, cotton, and nylon codends	Escapement through forward parts of net Validity of covered codend method
Priscilla V	6	Nov. 16-23 1954	Selection of redfish by manila codends	
Albatross III	59	Apr. 6-12 1955	Selection of haddock by manila codends	
Albatross III	64	Aug. 23-Sept. 2 1955	Selection of redfish by manila codends	Validity of covered codend method Meshing of redfish
Pairtows[1]	1	Oct. 12-28 1955	Selection of haddock by nylon and cotton codends	Fishing efficiency of large mesh nets Validity of paired tow method
Albatross III	74	May 2-10 1956	Selection of haddock by nylon and dacron codends	
Pairtows[1]	2	July 23-Aug. 4 1956	Escapement of haddock through forward parts of the trawl	Wire mesh codend escapement

[1]) Joint cruise of the *Albatross III* and *Delaware*

Fig. 1. Measuring haddock with aluminum "punch-strip."

Measurement of Fish

We used the total distance from tip of snout to median ray of caudal fin (fork length) in measuring all species. The resulting measurements were recorded to the "centimeter below"; *e.g.*, all fish from 29.0 to 29.9 are assigned to the 29 cm interval. Lengths which have been converted to the true mid-point of the cm interval (*i.e.*, 0.5 cm added) are marked with an asterisk (*) throughout the series.

The great quantities of fish handled in these experiments required the use of a rapid measuring method. For this reason we used the "punch-strip" system; *i.e.*, the recording of each fish length by a mark on a thin aluminum strip (see Figure 1). The frequency distribution of 400 or more fish in a well distributed length group can be recorded on a single strip. The lengths are subsequently tabulated from the strips through use of a transparent overlay, graduated in one centimeter intervals.

Sampling Procedures

Since the experiments were generally carried out in a manner to approximate comercial fishing practice the catches were sometimes very large, and in such cases we were able to measure only a portion of the fish taken. Sampling by aliquot was avoided where possible, but was necessarily resorted to in the silver hake work. Where sampling was required, the catch was randomly distributed into lots of equal size through use of baskets varying from one to three bushel capacity. The number of lots depended on the size of the catch and work requirements, the latter usually permitting the measurement of at least 400 fish. One lot (an aliquot) was measured, the remainder discarded, and the length distribution for the catch increased by a factor representing the total number of lots.

For the purpose of determining the amount of error introduced by sampling, two catches of silver hake were divided into lots and the fish in each lot measured. The mean lengths and total numbers of fish for each of the two series of seven lots are given in Table 2. Also included for each series are the deviations of lot mean from series mean, from which it is possible to adjudge the validity of the sampling procedure.

TABLE 2. Results of Sampling Validity Study for Silver Hake.

Lot Number	1	2	3	4	5	6	7	Total
Series I:								
No. of Fish	126	117	105	111	117	105	129	810
Mean Length cm	31.0	31.2	32.0	31.2	31.8	31.8	30.6	31.3
Deviation of Lot mean from Series Mean	—0.3	—0.1	+0.7	—0.1	+0.5	+0.5	—0.7	
Series II:								
No. of Fish	115	108	108	108	98	113	97	747
Mean Length cm	33.3	32.7	31.7	32.5	32.5	32.5	33.2	32.6
Deviation of Lot mean from Series Mean	+0.7	+0.1	—0.9	—0.1	—0.1	—0.1	+0.6	

The average deviation of lot mean from series mean was 0.4 cm in both cases, with a maximum deviation of 0.9 cm (Series II, Lot 3) from which we concluded that the mean for the whole catch could be estimated within 1.0 cm by a single bushel sample. Nevertheless, we made it our practice to measure three or more bushels since every trawl tow constitutes an individual experiment in covered codend work. It was necessary to obtain reliability of data sufficient to guarantee valid results for individual tows, so that the differences between them could be reliably interpreted.

Fig. 2. Pressure-indicating mesh gauge of the type recommended by ICNAF.

Mesh Measurement

All meshes were measured with the gauge developed by the author and later recommended by ICNAF as the approved type for enforcement of regulations. This gauge, illustrated in Figure 2, is 2 mm thick and has a taper of 1 to 4. It was designed to provide for a minimum of variation in measuring through the use of a pressure indicating device. The model shown indicates the inner mesh length in eighths of an inch under any desired pressure up to 15 lb. We used the 12-15 lb. pressure recommended by ICNAF in our work. Mesh measurements were always taken soon after the net was hauled in order to most nearly approximate actual "working-size."

For codends, we measured one continuous series of meshes from one end of the codend to the other. In cases where the codends were over 75 meshes in length we measured alternate meshes of the series. We have converted our mesh measurements originally taken in inches, to millimeters for convenience of analysis and comparability with results of other workers.

Description of Vessels Employed

Our experiments were conducted at various times aboard the five vessels listed below:

Vessel	Type	Length (ft.)	Horse-power	Gross Tonnage
Albatross III	Research Vessel	179	805	340
Delaware	Research Vessel	139	735	303
Priscilla V	Commercial Dragger	57	165	42
Michigan	Commercial Trawler	105	550	203
Wisconsin	Commercial Trawler	110	900	226

Description of Otter Trawls

The *Michigan*, *Wisconsin*, *Albatross III*," and *Delaware* used the standard "Number 41 Yankee" manila trawl of 5 inch mesh (knot-center size). *Priscilla V* used a "Number 35" cotton trawl of $2\frac{1}{2}$ inch mesh (knot-center size) modified for silver hake fishing through use of an oversize lower belly. These trawls are shown in Figures 3 and 4.

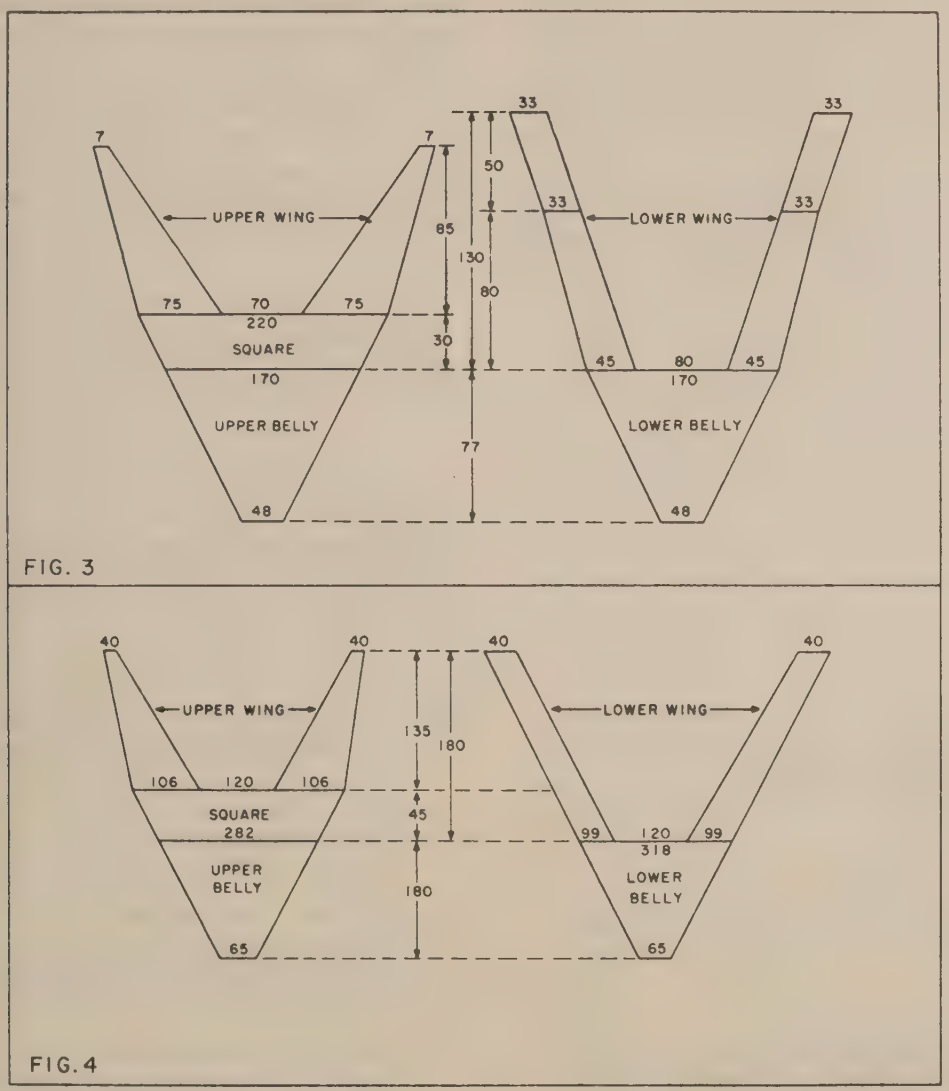

Fig. 3. Standard "Number 41 Yankee" trawl (manila). Dimensions in numbers of meshes of 5 inches (127 mm) between knot centers.

Fig. 4. Modified "Number 35" whiting trawl (cotton). Dimensions in numbers of meshes of $2\frac{1}{2}$ inches (63 mm) between knot centers.

Description of Covers

The covers used on the codends varied somewhat in dimensions, material, and mesh size, but usually were of 38 mm ($1\frac{1}{2}$ inch) cotton mesh, rigged to allow about 20% slack transversely (relative to the codend) to allow the netting to stand well away from codend meshes. The lower side of the codend was covered by chafing gear of some sort, usually hides, for most of its length. The bag or "cod-end" of the cover was 8 to 12 feet long, and joined at its upper side to the cover and at its lower side to the upper side of the codend, a few meshes ahead of the lachets. This method of attachment provided for maximum ease of handling, in that the codend could be emptied independently of the cover bag. The typical codend cover rig is illustrated in Figure 5.

In some instances the top bellies were also covered wholly (Figure 5A) or partially (Figure 5B). The material and general methods of attachment were the same as for the codend covers.

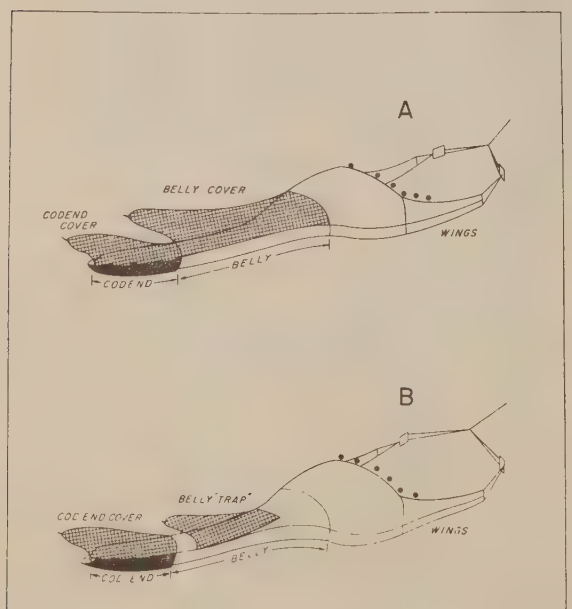

Fig. 5. Diagrammatic representation of codend cover, belly cover (A) and belly "strap" (B).

Area of Operation

The haddock work was all carried out in the Georges Bank area (Division 5Z) with the exception of *Albatross III* Cruise 59 which was carried out in the Browns Bank area (4X) and some incidental data collected in Massachusetts Bay (5Y) during the *Priscilla V* silver hake cruises.

The redfish work was carried out in various parts of the central Gulf of Maine by the *Priscilla V* and in "the Gully" near Sable Island (4W), in the vicinity of Browns and LaHave Banks (4X), and in the vicinity of Cashes Ledge (5Y).

The silver hake work was carried out in Massachusetts Bay and vicinity with the exception of some incidental results obtained from *Albatross III* cruises to Georges Bank.

Definition of Terms

A somewhat specialized vocabulary has been built up around the subject of gear selection. In the following list we have attempted to provide definitions for the terms of long standing as well as those to be introduced for the first time in this series.

Alternate tows. A variation of *Replicate tows.*

Bar. The component of a mesh which includes one knot and the twine extending to, but not including, the next knot; four bars make up a complete mesh. Thus the expression "bar measurement" (or "on the square") which is half the knot-center measurement.

Chafing gear. Any material, such as netting, hides, canvas, etc., attached to the trawl to prevent abrasion of the netting; usually used in reference to the codend.

Codend. The terminal portion of an otter trawl in which the catch is retained and lifted aboard, consisting of a long tube of netting of comparatively small cross section, attached to the after end of the belly, which may be opened at its terminus for removal of the catch.

Covered net method. The method of determining the escapement of fish from otter trawls by

capturing the escapees in a second layer of netting of smaller mesh applied over the primary netting of the trawl. The covering netting is fitted loosely to allow the fish to escape unhampered from the primary netting and usually terminates in a collecting pocket similar to a codend. This method is most often used on the codend, although covers have been used on certain forward parts of the netting also.

Double codend. (*See* Multiple codend.)

Double twine. A method of fabricating netting in which the meshes are made from two individual pieces of twine knotted together (*cf.* single twine).

Escape factor. The factor relating the length of fish escaping to the size of mesh from which they escape:

$$\text{E.F.} = \frac{\textit{Length in mm}}{\text{Internal mesh size in mm}}$$

Escapement curve. A variation of *Selection curve.*

Fifty percent point (also *fifty percent escapement* or *retention length*).
The length of fish at which 50% are retained by a particular fishing gear and 50% escape. Other points are similarly used but must specify "escapement" or "retention"; *ergo* 25% *escapement* length or 70% *retention* length.

Girth factor. The factor expressing the relation of length to maximum girth:

$$\text{G.F.} = \frac{\text{length}}{\text{maximum girth}}$$

Internal mesh size. The distance between, not including, opposite knots of a fully elongated mesh.

Knot-Center size. (*See* Knot-to-Knot size.)

Knot-to-Knot size. The distance between any two equivalent points of the knots at opposite ends of a fully elongated mesh. Often expressed as "knot-center" size, although the measurement may be taken between any other equivalent points of the two knots.

Longitudinal mesh measurement. Measurement of internal mesh size through use of an instrument which elongates the mesh by applying force to each end of the mesh (knot) parallel to the face of the mesh (*cf.* vertical mesh measurement).

Masking effect. The obstruction, or partial obstruction, of the meshes of a trawl by a cover used for determining escapement, such that fish are to some degree prevented from escaping. Generally, any effect of a cover in reducing escapement.

Mesh gauge. Any device used to measure the dimensions (usually internal) of a mesh. Present styles are classified as longitudinal mesh measurement gauges or vertical mesh measurement gauges.

Mesh index. The index expressing the relation between mesh shape and fish cross-sectional shape: $1.0 > \text{M.I.} = \text{A/B or B/A}$, where A = fish breadth/fish depth, and B = mesh length/mesh width.

Meshing. The ensnaring of fish by meshes resulting from their becoming ensnarled by and lodged within the meshes.

Multiple codend (also *e.g.*, double codend). A codend constructed of multiple layers of netting, usually of two layers (double codend), although instances of three layered (triple) codends have been reported.

Paired tows. A variation of *Replicate tows.*

Ply. (*See* Strand.)

Potential escape index. The index determined from girth factor and mesh index which expresses maximum possible escapement for a species from meshes of given shape:
P.E.I. = G.F. x M.I.

Replicate tows. Tows of trawls in series of two each, the design being such that the two members of each pair approximate each other in space and time as nearly as possible, in order to equalize all factors except a particular difference in the construction or operation of two nets with the object of isolating and measuring the difference. Two variations are: *Paired tows*, in which the two gears are towed at the same time, often by two different boats; and *Alternate tows*, in which one

boat fishes first with one gear variant and then with the other.

Retention curve. A variation of *Selection curve.*

Runnage. The specification of twine determined by its length per unit weight; *e.g.* 50 yd/lb or 450 ft/lb. It may be expressed by length for a known standard weight; *e.g.* "50-yard twine." The numeral alone may be used preceding the virgule (/) in abbreviated forms expressing runnage and number of strands; *e.g.* 50/4 twine.

Selection. In reference to fishing gear, the mechanism by which fishes with certain characteristics are captured and others escape; usually in reference to the selection of certain sizes of particular species.

Selection curve. A curve, often sigmoid, fitted to points representing the percentage of fish either retained by the gear or escaping from it at each size interval; more specifically, *Retention curve* if retained percentages are used, *Escapement curve* if escape percentages are used.

Selection factor. An index, related to *Escapement factor*, expressing the relation between the 50 percent point and the size of the mesh involved:

$$\text{S.F.} = \frac{\text{50 percent point}}{\text{internal mesh size}}$$

Usually used for codends of trawls; mesh size most often average for whole codend.

Selection range. The range in fish lengths over which a fishing gear exercises selection.

Selection span. A term expressing the range between 25 and 75 percent retention lengths, analogous to the interquartile range of a normal curve.

Selectivity. The selection properties of fishing gear; usually referring to the sizes of fish selected by the gear from the available population.

Single twine. A method of fabricating netting in which the meshes are made from a single piece of twine (*cf.* double twine).

Strand. (also *Ply, Thread, Twist.*) The smallest continuous component of which a twine is made, composed of comparatively short fibers if of natural material. Two or more strands are usually twisted (or braided) together to make a twine – thus *3-strand twine.* In abbreviations of twine characteristics the number following the virgule (/) indicates the number of strands.

Thread. (*See* Strand.)

Twine. Cordage used in fabricating netting, which is made by braiding or twisting together several strands.

Twist. (*See* Strand.)

Vertical mesh measurement. Measurement of internal mesh size by inserting into it a measuring instrument, usually in the form of a flat, tapered blade, graduated in appropriate size intervals. The vertical force applied elongates the mesh and is often controlled through use of a spring and the instrument therefore termed "pressure gauge."

B. ESCAPEMENT OF FISH THROUGH VARIOUS PARTS OF THE TRAWL

Abstract

Haddock are shown to escape primarily through the upper part of the after portion of the codend of otter trawls. Of the small numbers that escape through forward parts of the trawl, an estimated 10% do so through the top belly, 30% through the lower belly, 60% through the lower wings, and none through the square and top wings.

Silver hake escape through forward meshes to a greater extent than haddock. Silver hake also differ in that they are shown to escape through the lower side of the codend to a greater extent than haddock.

Introduction

The codend is usually considered to be the important escape area of the trawl and most available selection data concern codend escapement. Just what part of the codend is most used by the fish in escaping through meshes has not been known. An increasing collection of experimental data shows that fish of many species also escape through forward parts of the net. Material is presented in this paper which bears upon the problem of escapement of silver hake and haddock through various parts of the trawl.

Escapement Through the Codend

Various methods are available for the purpose of determining the effective escape area of the codend. A codend cover may be used over individual parts of the codend and catches compared with those with a cover over the whole codend. In another method the codend may be covered with a series of individual "pockets" covering sections of the codend, each retaining the portion of fish escaping through the section covered. Another approach to the problem is to use different mesh sizes in various parts of the codend and rearrange these to determine the effect upon escapement.

Michigan 2: The meshes in the after ends of codends beyond the splitting strap tend to enlarge with use. This causes a disparity in size between the meshes at each end of the codend.

We have noticed that if such a codend is reversed, putting the smaller meshes at the after end, the escapement of fish decreases. We are therefore led to believe that fish are escaping in greatest numbers through the after meshes.

When a double manila codend of 105 mm mesh was reversed during the *Michigan 2* experiments the selection factor for haddock first dropped from 3.1 to 2.8 and then returned to the original value as the after meshes (previously forward) increased in size. The results are briefly summarized below:

	Before Reversal, Average of 14 tows	After Reversal			
		Tow 1	Tow 2	Tow 3	Tow 4
Average mesh size for whole codend (mm)	105	106	110	111	113
Mesh size for the last one-quarter of codend only (mm)	111	98	105	106	114
50% point (cm)	32.3*	29.2*	32.7*	34.1*	35.2*
Selection factor	3.1	2.8	3.0	3.1	3.1

The difference of 3 cm in 50% point between the first series of tows and the first two with reversed codend is certainly due to the smaller meshes being positioned at the after end of the codend.

Albatross Cruise No. 74: When a single braided nylon codend of 122 mm mesh size was reversed during Cruise No. 74 of the *Albatross III*, the selection factor for haddock increased from 3.1 to 3.5 (p. 74). This codend had been used previously, and the meshes had enlarged at the after end. We did not fully realize the importance of the difference in mesh size between the two ends of the codend (119 and 113 mm) while rigging the gear, and the larger mesh end was attached to the belly.

With the codend in this abnormal position, the low selection factor was obtained (3.1), and the reversing was done to put the large meshes at the after end, which is more in line with normal commercial practice. Catches were small and mesh size did not change significantly during the experiments.

We were again led to the conclusion that haddock tend to escape through the after end of the codend.

Pairtows II: In the course of what we refer to as the Pairtows II experiments (the 2nd joint cruise of the *Albatross III* and the *Delaware*), we made a series of tows from the *Albatross III* in which various portions of the upper side of a double manila 45/4 codend were covered. In each case the cover extended from side lacing to side lacing. The lower side was covered with hides. The codend was 44 meshes in length and the mesh size averaged 123 mm. The following series were carried out:

Series	I	(9 tows)	all 44 meshes covered (whole codend)
Series	II	(4 tows)	last 22 meshes covered (1/2 of the length of codend)
Series	III	(3 tows)	last 16½ meshes covered (3/8 of the length of codend)
Series	IV	(2 tows)	last 11 meshes covered (1/4 of the length of codend)

The data for individual tows are given in Tables F-1 and F-2). Retention curves for each series are shown in Figure 6. We see from the figure that reducing the cover to 22 meshes reduced the 50% point by about 1.5 cm. The reduction to 11 meshes reduced the 50% point by another 1.0 cm. The 16½ mesh cover, however, has a 50% point even higher than the full cover. A reason for this and for the entirely different shape of the curve cannot be provided. If we exclude the 16½ mesh cover anomaly it appears that the decrease in 50% point (indicating lower escapement) has been caused by fish escaping through parts of the codend which are not covered.

We can gain some information on the importance of various parts of the codend by comparing the percentage of fish of various sizes which entered the 11, 22, and 44 mesh covers. The percentages in Table 3 have been read from Figure 6.

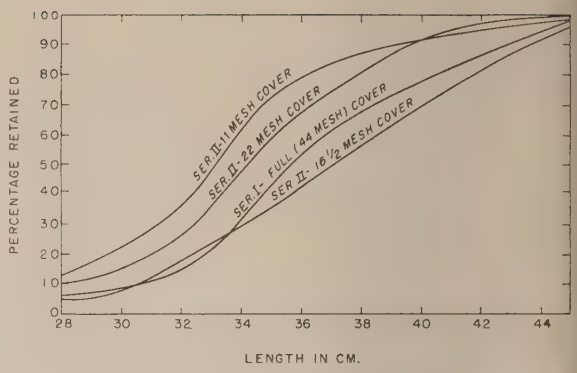

Fig. 6. Selection curves for 44 mesh (full) cover and 22, 16½, and 11 mesh covers.

TABLE 3. Percentage of Total Catch in Cover for Series I, II, and III.

Fish Size (cm)	Percentage of total catch in: Ser. I-44 Mesh Cover	Ser. II-22 Mesh Cover	Ser. III-11 Mesh Cover
<29	95	90	88
29	93	88	83
30	92	84	78
31	89	80	71
32	85	73	63
33	79	63	52
34	68	52	38
35	57	42	28
36	47	32	20
37	38	25	15
38	32	13	12
39	26	14	10
40	21	8	8
41	17	4	7
42	13	2	5
43	9	1	4
Mean	54	42	36
% of 44 Mesh Cover	—	78	67

From the 44 mesh cover figures we see that for every 100 fish of 29 cm entering the codend, for instance, 93 entered the cover. Only 88 out of every 100 fish taken were in the 22 mesh cover. The 11 mesh cover in like fashion caught only 83. We may assume that the difference between these figures represents the number of fish escaping through the uncovered parts of the codend. Thus out of 100 fish of 29 cm which entered the codend, 83 escaped through the 4th (terminal)

[1]) Tables marked F are not printed in the paper but filed in the ICNAF Secretariat for reference.

quarter of the codend meshes, 5 escaped through the 3rd quarter of meshes, and 5 escaped through the 2nd and 1st quarters. We may conclude, therefore, that approximately 90% (83 out of 93) of the escapement takes place in the terminal one quarter of the codend. If we apply this reasoning to fish of 36 cm for example, we discover that 20 escape through the 4th, 12 through the 3rd, and 15 through the 2nd and 1st quarters. We then conclude that about 43% (20 out of 47) of those which escaped did so through the terminal quarter. We may estimate, in like manner, that 38% of the escapement by 42 cm fish takes place through the terminal quarter. We can also make a combined estimate for all the size groups represented by using the means for each cover. Thus out of 100 fish of 43 cm and lower entering the codend an estimated 54 escape. Of these 54 which escape, 67% do so through the 4th, 11% through the 3rd, and 22% through the 2nd and 1st quarters combined.

No good reason offers itself to explain why a higher proportion of smaller than of larger fish which escape should do so through the terminal part of the codend. It may be owing to greater swimming power for large fish or to some differential behaviour in the net; or perhaps it is an artifact of the escape calculations made above.

It may be argued, however, that even if all the escapement took place in the after part of the codend, we could still obtain reduced numbers in the cover by just moving it rearwards. This could come about by the shortened cover not having length enough from its place of forward attachment to permit it to rise up clear of the codend, even at its terminal quarter. This source of experimental error presumably could in itself cause masking and thus reduce the cover catches. Our other data and our observations of covered rigs underwater with television, however, suggest that this is not a significant source of error.

Albatross cruise No. 51: A series of tows with a full cover (Series I) and a half-cover (Series II) [1] was conducted during Cruise No. 51 of the *Albatross III* in June 1953. The codend was of 45/4 double manila mesh which averaged 75 mm in size. The data for each of the 4 tows with the half-cover are given in Table F-3 along with a summary of 14 tows with a full cover. The selection curves are plotted for each series in Figure 7. We see from the figure that the half-cover results indicate *higher* apparent escapement than the full cover results. If many fish were escaping through the forward half of the codend we would expect the half-cover to show *lower* escapement. Why it should show the opposite is not easily explained. Nevertheless, we can find no evidence in these results to suggest that the forward half of the codend is of importance in the release of haddock.

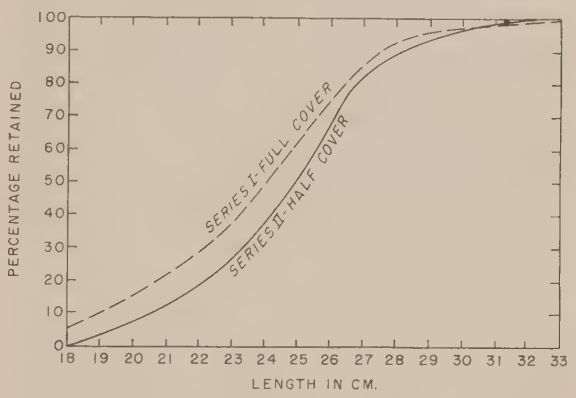

Fig. 7. Selection curves for full cover (Ser. 1) and half-cover (Ser. II) with 75 mm mesh codend of 75/4 double manila.

Albatross cruise No. 49: During Cruise No. 49 of the *Albatross III* in May 1953, we carried out an investigation of the escapement through the lower side of the codend. The experiment consisted of two series of tows one with and one without bull hide chafing gear on the lower side of the codend.

During both series we were also varying the length of tow for another purpose (*see* p. 55). As the number of tows of each length were about equally represented we feel that no important effect upon these results was caused.

In Series I we made 14 tows with hides and 10 tows without hides. The 50/4 double manila codend used had a mesh size of 123 mm during the "with hides" tows and 124 mm during the

1) In this series the cover extended over exactly half the length of the codend (the terminal 12 ft.).

"without hides" tows. The individual tow results are given in Table F-26. A summary of "without hides" and "with hides" results is provided in Table F-4.

We see from Figure 8, wherein the two selection curves are plotted, that the proportions of fish in cover and codend in the "with hides" and "without hides" tows do not differ greatly. If large numbers of fish were able to escape through the lower side with hides removed, fewer fish would enter the cover and the percentage "retained" would appear much higher. This took place to a limited extent throughout the 30 to 60% range, and as a result the 50% point (39.6 cm*) and selection factor (3.2) appear slightly lower for "without hides" tows. Although the 50% point is at a lower size, higher escapement is indicated at each end of the "without hides" curve. We cannot conclude from this study, therefore, that the underside of the codend is of much importance in the escapement of haddock.

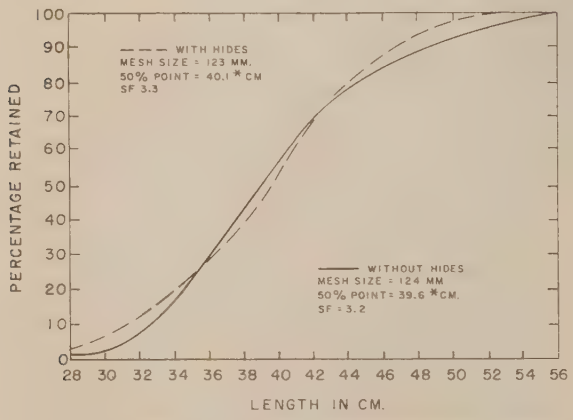

Fig. 8. Selection curves for "with hides" and "without hides" tows. Series I.

In Series II the study was continued with a double manila codend of smaller mesh size in a series of 8 "with hides" and 5 "without hides" tows. The mesh size was increasing throughout the experiment and averaged about 71 mm during the "with hides" tows and 75 mm for "without hides" tows. The individual tow results are given in Table F-27. A summary of "without hides" and "with hides" results is given in Table F-5. The selection curves are

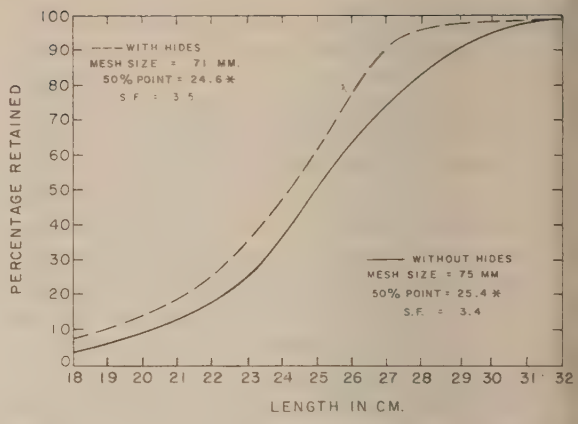

Fig. 9. Selection curves for "with hides" and "without hides" tows. Series II.

plotted in Figure 9. We see that greater proportions of fish of all sizes occurred in the cover during the "without hides" tows, but the mesh size had increased 4 mm over the "with hides" tows. The selection factor corrects for this and shows the "with hides" tows (3.3) to have more fish in the cover than the "without hides" tows (3.2). The selection factor is dependent only upon the 50% point, however, and the two curves have different shapes, as in Series I, so the same effect does not hold over the range of lengths. An escape factor calculated for the 85% retention point, for instance, is actually the same for both (3.8). We cannot, therefore, conclude from these data either that important quantities of haddock escape through the underside of the codend.

Priscilla V: In the *Priscilla V* experiments we were primarily concerned with the escapement of silver hake. Because the escapement of this species was much lower than expected, we attempted many modifications to the gear. One of these modifications provided data relating to the escapement through the lower side of the codend.

The codends tested during the *Priscilla V* work normally had covers only on the upper side. The after 12 feet of the lower side was partially covered with discarded codend netting as chafing gear. In order to test whether low selection factors obtained might be owing to large numbers escaping through the incompletely blocked lower side meshes, we applied additional fine mesh

netting over these meshes. The primary purpose of this modification was to prevent passage of fish through the lower side, but we discovered that the additional covering meshes were functioning as a regular cover, even though very little slack was provided, and considerable numbers were thus taken in this "lower cover." The codend used was made of single, twisted, 125/3 nylon of 103 mm mesh size.

The catches of silver hake for 3 tows with both upper and lower covers are given in F-6. The data show that about one-fifth of the 4,428 silver hake that escaped did so through the lower side. We have shown elsewhere (p. 34) that little effect upon the selection curves results from using covers only on the upper side.

The lower cover was constricted at its median point by the attached chafing gear and catches of escapees from the forward and rearward parts did not mix. Although we did not separate catches in the separate parts of the lower cover, we observed that catches were about equally divided between the two. Thus, lower side escapement of silver hake appeared to take place equally in forward and after parts of the codend.

Remarks: These studies indicate that for haddock the important escape area of the codend is the after part of its upper side. Thus, no major error is likely to be caused by determining escapement from covers applied only to the upper side even if parts of the lower side of the codend are not covered with chafing gear.

Although haddock do not appear, from indirect reasoning, to utilize the lower side of the codend for escapement, more direct evidence available indicates that about one-fifth of the silver hake escapement takes place there. It is possible that some haddock, yet not enough to affect the selection curves, may in fact escape through the underside of the codend. This is not of great practical importance, however, as in haddock fishing the whole underside is usually obstructed with bull hide chafing gear. Silver hake codends are more frequently protected with discarded pieces of codend netting which would permit escapement to take place.

Underwater television observations have shown that haddock which escape usually do so while the net is under tow. Silver hake on the other hand appear to escape in large quantities in hauling back after the way is off the net, but considerably before it reaches the surface. Thus we have come to believe that there are important differences in the escapement behaviour patterns of the two species.

We have shown elsewhere (p. 68) that escapement may be diminished when catches are heavy. This may be due in part to blocking of the normally larger after meshes which would force the fish to escape through smaller meshes. We have also shown that more consistent results are obtained in some instances by relating escapement to mesh size in the after part only of the codend.

Escapement in Forward Parts of the Trawl as Shown by Covers

Gear and Methods: The application of covering mesh over the forward parts of otter trawls is made difficult by the very expanse of the meshes involved; *e.g.*, the upper belly has about 20 times as many meshes as the upper side of the codend. Differences in configuration of the forward sections of the trawl also militate against the use of covers. We were, however, able to apply covers successfully to the upper belly in several instances.

In experiments board the *Albatross III* (Cruises 49 and 51) we used a full cover over the belly of the starboard trawl and a partial cover ("belly trap") over the belly of the port trawl. The codend was covered in both cases. (*see* p. 29 for descriptions of covers.) The cover was made of 35 mm mesh, 15 thread cotton. The 130 mm mesh belly was of 125/4 manila (single) at its forward end and 75/4 manila (single) at its after end.

During several cruises of the *Priscilla V* we employed a cover over the whole square and top belly. The covering mesh was 15 thread cotton of 35 mm mesh size. The belly was of 57 mm. mesh, 24 thread cotton throughout. The cod ends were of 85 mm, 400/3 nylon and 73 mm 72 thread cotton.

Covers applied to the upper wings at various times failed to produce catches. This we believe may be owing in part to the configuration of the trawl and design of the cover but primarily to lack of escapement in this part of the trawl.

Results, Albatross III Experiments: Two series of tows are available for the full belly cover used on the *Albatross III*. We completed 28 tows successfully in Series I, and 11 in Series II. These results are given in Table F-7.

Escapement of haddock from the top belly was found to be much lower than through a codend of the same mesh size. For example, 3% of 32 cm haddock escaped from the belly in Series I and 1% in Series II, while about 90% of 32 cm fish will escape from a codend of the same mesh size.

Catches in the belly cover represented only 8% and 9% of the numbers taken in the codend cover. As there are only 1/20 as many meshes in the upper belly as in the upper side of the codend we see how ineffective the belly meshes are in releasing haddock.

The smaller cover or "belly trap" caught very few haddock. A total of 35 fish, of 21-37 cm length, were taken in it in 24 tows. The combined catch of codend and its cover for these tows was 10,716 fish within the 21 to 37 cm range. As the belly trap covered only 11% of the belly area, the escapement of 35 fish would, of course, be an underestimate. The total escapement from the belly can be estimated from direct proportion of belly area covered to total belly area. This would give an estimate of 318 escaping or about 3% of the total catch of 10,716 fish of 21 to 37 cm. In Series I and II the full cover took 8% and 9% of the numbers of those sizes caught. The belly trap is then either operating at a lower efficiency or else escapement of haddock through the portion covered by the trap is proportionately less than through other parts of the belly. The full belly cover results are considered the more reliable.

Priscilla V Experiments: The results for the series of tows carried out with a cover over the whole square and belly of the cotton trawl are given in Table F-8. Escapement of silver hake from the top belly and square is much less than escapement from a codend of equivalent mesh size. For instance, only 18% of the 14 cm fish escaped from the top belly and square while about 70% of 14 cm fish would escape from a cotton codend of the same mesh size. The smallest fish are apparently escaping in large numbers. However, all fish of less than 10 cm are being taken in the belly cover. We have shown elsewhere (p. 82) that fish up to 12 cm are escaping through the 35 mm covering mesh. Our records of the catches of the smallest fish are thus underestimated.

Escapement through Forward Parts of the Trawl as Shown by Replicate Tows

Covers can be used with some success for determining escapement through the top belly and square but cannot be expected to work well on wings and lower belly. We have, therefore, used the replicate tow method to extend our studies to these parts.

Methods: A series of paired tows was carried out during Operation Pairtows, a joint cruise of the *Albatross III* and *Delaware*. The two vessels, of similar fishing ability, attempted always to fish their nets simultaneously. They usually succeeded in this, setting and hauling back within a few minutes of each other. The two nets were towed for equal periods of time and as closely together as safety would permit.

Care was taken to assure that the No. 41 nets used by each were rigged in identical manner. We used on each net the same size and weight of "doors", number of floats, and length of headline and footline. Netting components and other attachments were of the same specifications; the only difference was in mesh size. Four series of tows were carried out:

Series I The *Albatross III* and *Delaware*, towed nets of identical mesh size (120 mm.) to determine the fishing power of the two units for various sizes of fish. Both codends were of 63 mm mesh size. (The *Delaware* continued towing the 120 mm trawl through Series II to IV.)

Series II The *Albatross III* had 55 mm mesh in the square and top wings in place of the 120 mm mesh of the *Delaware*.

Series III: The *Albatross III* used 55 mm mesh in all parts except the lower wings.

Series IV The *Albatross III* used 55 mm mesh in all parts of her trawl.

In Series V the *Albatross III* made alternate tows of her own port and starboard nets with 120 mm and 55 mm mesh respectively throughout the forward parts. Double manila codends of 63 mm were used in both trawls.

In addition to the above experiments a series of alternate tows was conducted by the *Priscilla V* for silver hake. A trawl of 57 mm mesh was fished from the port side and one of 84 mm mesh from the starboard side of the vessel. The codends were both of 40 mm mesh.

Results, Pairtows Series I: We intended, by reducing the amount of known variables, to eliminate bias caused by different catching rates of the *Albatross III* and the *Delaware*. To ascertain whether, in fact, the two vessels were normally catching proportionately equal numbers of all sizes we conducted a series of standardization tows. Thus, two groups of paired tows were made with identical manila trawls. The results from the two groups are given in Tables F-9 and F-10. The length compositions for the two series are shown in Figures 10 and 11.

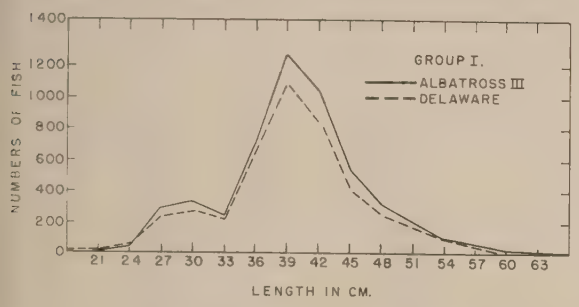

Fig. 10. Numbers of haddock of each length taken by the *Albatross III* (5122 ind.) and *Delaware* (4364 ind.) in standardization tows, Series I.

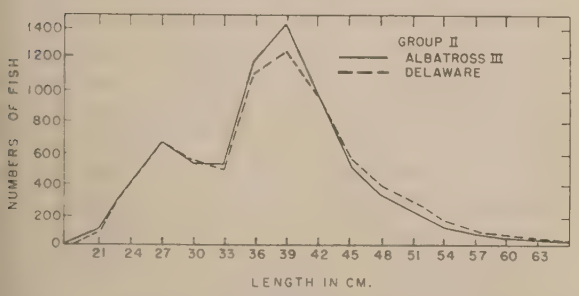

Fig. 11. Numbers of haddock of each length taken by the *Albatross III* (7103 ind.) and *Delaware* (7073 ind.) standardization tows, Series II.

We see from the figures that the proportions of various lengths taken by the two vessels are nearly identical, although the *Albatross III* caught greater total quantities of fish. On the basis of the similarity of the length distributions we proceeded to test the escapement through various parts of the trawl although we realized that some biasing effect might be caused by the differences in the total catches.

Pairtows Series II: With 55 mm mesh inserted in the top wings and square only, of the *Albatross III* trawl, we conducted a series of four pairs of tows. The results are given in Table F-11 and may be summarized as follows:

Length in cm	Number of Fish *Alb.*	*Dela.*	% "Retained" (*Dela./Alb.*)
17-22	39	40	103
23-25	218	324	149
26-28	1205	1403	117
29-31	1355	1941	143
32-34	477	628	132
35-37	926	748	81
38-40	1193	1109	93
41-43	803	859	107
44-46	229	336	147
47-49	95	94	99
50-66	92	61	66
TOTALS	6632	7543	

If the fish of the smaller sizes were passing through the top wings and square of the 120 mm mesh trawl (*Delaware*) and were prevented from doing so in the *Albatross III* trawl by the 55 mm mesh, then greater quantities of smaller size fish should have been taken by the *Albatross III* trawl. The results show that this is not so, and we may thus assume that escapement through the top wings and square is negligible. Why the *Delaware* actually caught more, rather than less, fish cannot be determined; her catching power was shown in the previous section to be lower than that of the *Albatross III*.

Pairtows Series III: With 55 mm mesh in the top wings, square, and top and bottom bellies of the *Albatross III* trawl we completed four pairs of tows. The results are given in Table F-12, and can be summarized as follows:

Length cm	Number of Fish *Alb.*	*Dela.*	% "Retained" (*Dela./Alb.*)	% Escaping
<24	26	9	35	65
23-25	370	227	61	39
26-28	1733	1508	87	13
29-31	1736	1798	104	—
32-34	508	548	108	—
35-37	459	563	123	—
38-40	563	832	148	—
41-43	311	505	162	—
44-46	104	206	198	—
47-49	21	31	148	—
50-52	24	15	62	—
>52	14	15	107	—
Total	5869	6257		

Greater numbers of the smaller sizes were taken by the *Albatross III*. The figures in the column headed % "Retained" *Delaware* of *Albatross* can be thought of as the percentage retention of the larger mesh. The converse figures to these, given in the next column, indicate percentage escapement. The only difference in gear between this series, where escapement is apparent, and the last series, where no escapement could be shown, is that 55 mm mesh was used in the bellies. The escapement shown must therefore be through the bellies and may be estimated for each length by the percentage "escaping" figures.

Pairtows, Series IV: We inserted 55 mm mesh into the lower wings for this series so that the whole trawl was of 55 mm mesh. Seven pairs of tows were completed. The results are given in Table F-13, and may be summarized as follows:

Length in cm	Number of Fish *Alb.*	*Dela.*	% "Retained" (*Dela./Alb.*)	% Escaping
17-22	68	8	12	88
23-25	951	318	33	67
26-28	3541	1705	48	52
29-31	3041	1861	61	39
32-34	780	519	67	33
35-37	734	576	78	22
38-40	972	1069	110	—
41-43	515	770	150	—
44-46	141	241	171	—
47-49	27	52	193	—
50-66	20	66	330	—
Totals	10790	7185		

That considerably greater numbers of the smaller sizes were taken by the *Albatross III*, indicates a high escapement through the 120 mm mesh. The only difference in gear from Series III was the insertion of 55 mm mesh in the lower wings. The difference between the percentages in the two series is thus a measure of the percentage escaping through the lower wings only. Calculating this difference we obtain the following estimate of escapement through the lower wings:

Length in cm	% "Escaping"
17-22	23
23-25	28
26-28	39
29-31	39
32-34	33
35-37	22
38-67	—

We see from the results of Series III and IV that much greater numbers of fish beyond the selection range are caught by the 120 mm mesh. This disparity is shown to increase as larger mesh is used. Thus the larger mesh appears to be operating more efficiently. This cannot be owing to a greater speed of tow as the two vessels were fishing side by side throughout.

A most interesting aspect of the results is the progressive increase in numbers taken by the larger mesh trawl, with increase in fish size, relative to the small mesh trawl. It thus appears that a single efficiency adjustment can-

not be applied to the catches of all sizes as has been done in so many replicate tow codend selection experiments.

Although the efficiency difference certainly affects the validity of the results, we must conclude that substantial numbers of small haddock escape through the lower wings and bellies of the 120 mm trawl. Adjusting the *Albatross III* catches upward on the basis of relative numbers beyond the selection range would result in *higher* apparent escapement than that already calculated.

Pairtows, Series V: A total of six pairs of alternate tows with 120 mm. (port) and 55 mm (starboard) nets was made by the *Albatross III*. The results are given in Table F-14, and may be summarized as follows:

Lengths in cm	Number of Fish 55 mm trawl	120 mm trawl	% "Retained" 120mm/55mm	% Escaping
17-22	89	69	78	22
23-25	220	215	98	2
26-28	424	360	85	15
29-31	350	464	132	—
32-34	453	391	86	14
35-37	791	777	93	7
38-40	777	825	106	—
41-43	479	565	118	—
44-46	302	400	132	—
47-49	232	225	97	3
50-75	372	393	106	—
Totals	4489	4684		

Contrary to the pair tows results, little escapement through forward parts of the net is demonstrated. We must consider the results of the paired tows of the two vessels as being the more reliable. It is probable, therefore, that the difference in results is owing to experimental error in the *Albatross III* alternate tow results. A major source of error could be the difference in speed of the two nets, the smaller offering more resistance and therefore slowing the speed of tow, which could cause the escapement to be underestimated. This did not occur in the paired tow work when the speed of towing of the two nets could be equalized with the *Albatross III* and *Delaware* towing side by side.

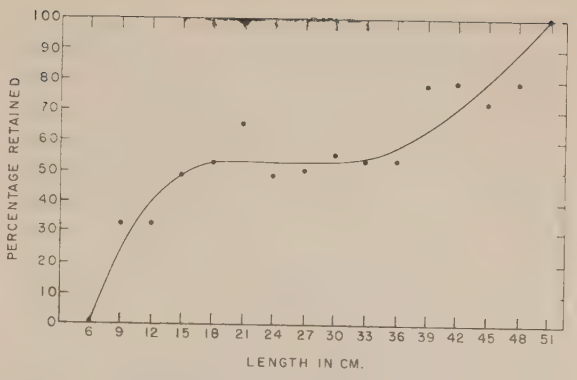

Fig. 12. Percentage "retained" by an 84 mm cotton trawl, silver hake.

Priscilla V.: A series of four pairs of alternate tows were carried out with 84 mm and 57 mm trawls to investigate the escapement of silver hake. The results are given in Table F-15. The data shows that the number of fish taken by the 84 mm net increases relative to the 57 mm net with increasing fish size. The results when plotted as a selection curve (in Figure 12) show that the 84 mm mesh allowed many silver hake to escape. The curve, however, does not take the form typical to codend escapement. Increasing retention is indicated from 6 to 15 cm and from 33 to 51 cm, but throughout the middle part of the range no selective effect is demonstrated. Fish of 18 cm, for example, appear no more likely to escape than fish of 36 cm.

The escapement is shown to be higher for sizes over 32 cm than for a codend of equal mesh size. Silver hake of over 40 cm have a girth larger (girth factor = 2.4) than the average mesh circumference (168 mm). Thus many of those shown to escape may be doing so only with considerable effort, or perhaps they are choosing the larger individual meshes for escape.

Summary and Discussion

We have seen through the course of this discussion that the most important escape area for haddock and silver hake is the upperside of the codend which contains only about one percent of the total number of meshes of the trawl. Haddock do not appear even to utilize all the meshes of the codend but rather restrict their escape efforts to its after one-quarter. In terms

of managing fisheries this means that control of the codend alone may be necessary, as the escapement within the selection range is, in fact, higher for the codend than for the total remaining area of the trawl. Fish prevented from escaping through the forward parts of the net would still be able to escape from the codend in all probability.

Haddock of lengths up to 37 cm are shown by replicate tow results to escape through forward parts of the 120 mm mesh trawl. The escapement determined for the whole trawl from replicate tows is much higher than that for the top belly determined from covers. In comparing the results from both, we can estimate that approximately 10% of the haddock which escape through the forward parts do so through the top belly. The alternate tow data show that about 40% of the forward escapement takes place in the bellies. Thus an estimated 30% escape from the lower belly. The remaining 60% are indicated to escape from the lower wings and none escape from the square and top wings.

The covered top belly (120 mm mesh) results show escapement of sizes of haddock up to 47 cm. The replicate tow results for both upper and lower bellies indicate escapement up to 28 cm only. This apparent discrepancy has probably arisen because of lower numbers of all sizes caught by the inefficient small mesh trawl as previously pointed out. Adjusting the small mesh curve to a catch equivalent to that of the large mesh would increase the apparente scapement and the discrepancy would be eliminated.

We discovered that the small mesh trawl offered much more resistance than the larger mesh trawl. In making paired tows with the two large mesh trawls, the *Albatross III* used 215-220 r.p.m. engine speed and the *Delaware* used 200-205. The *Albatross III* was required to reduce her speed by 10 r.p.m. (to 210) while towing the small mesh net to prevent overheating, and the *Delaware* was required to reduce her engine speed by 15 r.p.m.'s (to 190) in order for the *Albatross III* to stay abreast of her. In the *Albatross III* alternate tow experiment the same r.p.m.'s were used for each net. This explains partially at least, why the alternate tow results showed so much less escapement than the paired tow results.

Silver hake were shown to escape in great numbers through the forward parts of the net. The selection as shown by the cover results appears to be sharp through the 57 mm belly and square where relatively small fish were escaping. Selection as shown by the alternate tows appeared sharp for the small sizes through the whole 84 mm trawl and very dull for the intermediate sizes. Some fish with girth larger than mesh circumference were also shown to escape. Our other silver hake experiments (pp. 61 and 81) have shown the escapement of this species to be typified by unique characteristics. Certain of the differences are explainable only on the basis of psychological factors. In this study where fish of 16 cm were not escaping in greater numbers than fish of 36 cm, a certain indifference to capture is shown.

C. VALIDITY OF THE COVERED CODEND METHOD

Abstract

Eleven series of replicate tow experiments with covered and uncovered codends were carried out to determine the validity of the covered codend method.

For many experiments no effect of the cover was indicated; for others a definite reduction in escapement was shown and for some the reverse seemed true. In one instance modification of the gear appeared to eliminate the "masking" effect.

The conclusion drawn from the study is that properly controlled covered net experiments will give valid results.

Introduction

The "covered codend method" has proven to be the simplest experimental technique for determining the escapement of fish through codend meshes. This technique consists of applying covering netting of small size mesh around the

codend, either covering it entirely or only the parts from which fish are likely to escape (see p. 29). A covering of netting over the codend can be expected to reduce the escapement of fish if it is not properly rigged. Many investigators, questioning the validity of the covered codend technique, have employed more complicated methods for measuring escapement. Two such methods are the alternate tow method and the double codend (or "trouser trawl") method.

The alternate tow method requires the alternate towing of two nets which are identical except that one net is rigged with the codend to be tested and the other with a smaller mesh codend. The difference in the catches of the two nets represents the escapement from the larger mesh codend. The double codend method, which is based on the same principle, requires that two codends of different mesh size be attached to the same net. The difference in catches of the two codends represents the escapement.

Other less direct methods may be employed but all involve comparison of catches made with codends of different mesh sizes. The validity of techniques other than the covered codend method has been questioned chiefly because of the difficulties in insuring that equal numbers of fish of each size have actually entered the two codends to be compared. The data usually must be adjusted by some method to remove the effect of inequalities in total numbers entering the two codends. The adjustment is usually made by choosing an arbitrary 100% retention length and multiplying the length frequency of the catches of one codend or the other by a factor which will equalize the numbers above the 100% size. In using such an adjustment one must assume that the proportions of fish of each size entering the two codends are equal. The adjustments and assumptions employed in these experiments admit rather serious sources of error to the results.

Results obtained by different workers have varied considerably. Figure 13 (from Graham, 1952) demonstrates the extent of differences obtained from experiments on the escapement of haddock. This graph shows as complete a summary of 50% points as was available in 1952. The mesh sizes shown represent the best estimate of the internal size of the mesh and were converted from whatever dimensions the authors had given. Errors in estimating the mesh size alone could not have accounted for such great differences in results as are shown for the larger

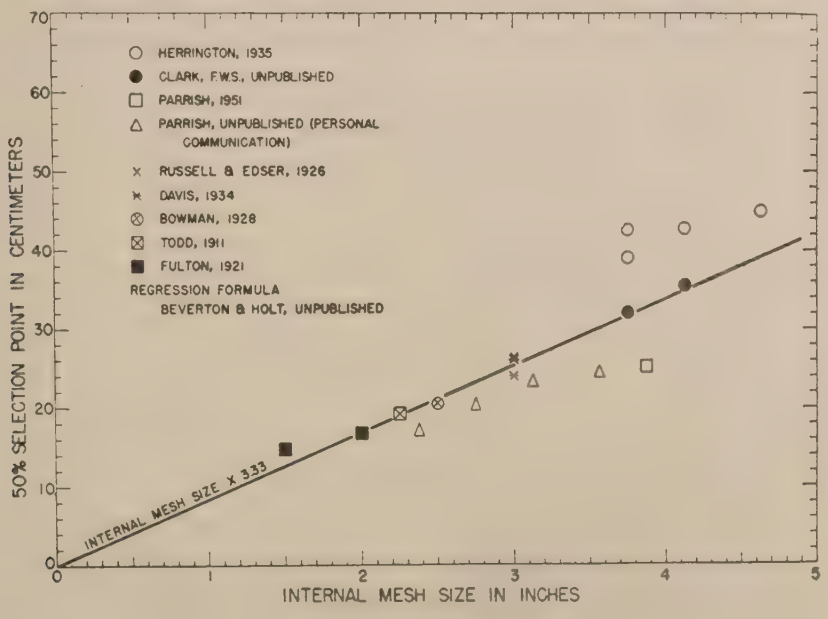

Fig. 13. Relation of size of mesh to size of haddock retained.

mesh sizes, however. At a mesh size of approximately 3.75 inches, Parrish's results indicate a 50% point at about 25 cm (Selection Factor = 2.6), Clark's results at about 32 cm (S.F. = 3.4), and Herrington's at about 43 cm (S.F. = 4.5). Clark used a cover over the upper side of the codend only, the under side being covered by hides. Parrish's method was essentially the same. Herrington's results were obtained by making alternate tows with large and small mesh codends and by using two codends of different mesh size on the same trawl (double codend method). Parrish worked in the Eastern Atlantic, Clark and Herrington in the Western Atlantic.

Because of the seriousness of these differences much of the time available to us for gear selection work since 1952 has been devoted to establishing the validity of techniques. It is the purpose of this paper to present the results obtained which bear on the validity of the covered codend method.

Methods and Gear

The validity of covered net results can be determined in many ways. The most widely used method has been that of replicate tows with codends of the same mesh size, with and without covers (Davis 1934, Parrish 1950, and others). To use this method without adjustments we must assume that random tow-to-tow differences in numbers of fish of all sizes entering the two codends have been equalized by a sufficient number of tows. It is possible, however, to adjust the data in the manner described previously for replicate tows with different codend mesh sizes, but this cannot correct for unequal proportions of various sizes entering the two codends. The catches in the covered and uncovered cod ends are subjected to analysis to determine if the numbers of fish of various sizes in the two catches are equal. If the cover is inhibiting the escapement of fish this will be shown by a greater number of fish of escape sizes in the covered codend catches.

The methods we used were generally as described above. Eleven series of experiments were carried out with codends of various mesh sizes and types. A summary of these experiments is given in Table 4. The vessels and their otter trawls are described elsewhere (p. 27).

TABLE 4. Summary of Experiments on the Validity of the Covered Codend Method.

Experiment	Species	Type	Mesh size (mm) cov. c.e.	Mesh size (mm) uncov. c.e.	No. of Pairs of Tows
Michigan No. 1	Haddock	50/4 manila, dbl.	92	93	7
Michigan No. 2	Haddock	50/4 manila, dbl.	105	104	5
Albatross III Series I – No. 51	Haddock	75/4 manila, dbl.	76	75	5
Albatross III Series II – No. 51	Haddock	75/4 manila, dbl.	76	75	9
Albatross III – 52	Haddock	45/4 manila, dbl.	113	114	10
Pairtows I Series I	Haddock	120th. cotton, single	138	144	5
Pairtows I Series II	Haddock	Braid, nylon, 43 yds./lb. single	135	128	3
Priscilla V Series I	Silver hake	96th cotton, single	73	72	4
Priscilla V Series II	Silver hake	400/3 twisted nylon, single	85	84	4
Priscilla V Series III	Silver hake	400/3 twisted nylon, single	82	82	9
Albatross III No. 64	Redfish	45/4 manila, dbl.	109	110	6

We have discovered, as have others, that it is not always possible to conduct this kind of experiment at sea according to a predetermined design. A certain amount of latitude must be allowed the experimenter in deciding which tows to accept and which to reject. It is obvious that if a net is badly damaged and the catch partially lost, the tow should be rejected. But more arbitrary judgments must be made on occasions of improper condition of gear, differences in location of gear, differences in location of tow due to tide, wind, course error, etc., and diurnal changes in abundance of fish. It is often not possible to make sufficient tows to compensate for differences in catch resulting from these factors and some tows must be rejected.

Results

Michigan, No. 1 - Haddock: Seven pairs of alternate tows were completed on the first cruise of the *Michigan*[1] in June 1952 with results as follows:

Codend	Towing Time Hrs. - Min.	Mesh Specifications Size (mm)	Type	No. of fish in: c.e.	cov.	50% Point (cm)
Covered	8 - 26	92	50/4 manila dbl.	5992	378	29.0*
Uncovered	8 - 45	93		6167	–	–

The numbers of fish of each length caught by the two codends are given in Table F-16. Length frequencies of the catches are plotted in Figure 14. We see from the figure that the characteristics of the catches from the two codends are quite similar. The catches are almost identical in magnitude, the differences being only about 3%. The mean lengths of fish caught in the two codends were identical (40.7 cm).

As any masking effect of the cover could only operate on the sizes within the selection range, the most pertinent comparison is probably of catches within the effective selection range (*i.e.*, smaller than 38 cm) only. The numbers of fish smaller than 38 cm were 1,939 and 1,979 for the covered and uncovered codends, respectively (difference of 2%). The mean sizes within the selection range were nearly the same, being 35.0 cm for the covered codend and 34.8 for the uncovered codend.

Only a small proportion of fish escaped into the cover because of the low abundance of the smaller escape sizes. No very pronounced effect upon the catches can be expected, therefore, and the results are of somewhat limited value. We can only say that these results give no evidence to support the theory that the cover restricts the escape of haddock through codend meshes.

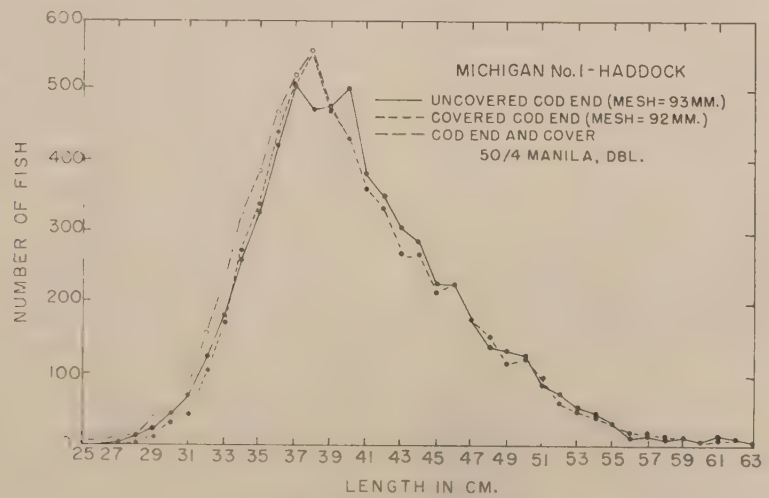
MICHIGAN No. I - HADDOCK
UNCOVERED COD END (MESH = 93MM.)
COVERED COD END (MESH = 92MM.)
COD END AND COVER
50/4 MANILA, DBL.
NUMBER OF FISH
600
500
400
300
200
100
25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63
LENGTH IN CM.

Fig. 14. *Michigan I* catches with covered and uncovered codends (7 tows, 12,157 ind.).

1) Preliminary results of the *Michigan* cruises were published by Clark (1952).

Michigan, No. 2 - Haddock: Five pairs of alternate tows were completed on the second *Michigan* cruise in June 1952 with results as follows:

Codend	Towing Time Hrs. – Min.	Mesh Specifications Size (mm)	Type	Number of fish in: c.e.	cov.	50% Point (cm)
Covered	5 – 35	105	50/4 manila	2861	519	32.3*
Uncovered	5 – 35	104	double	3026	–	–

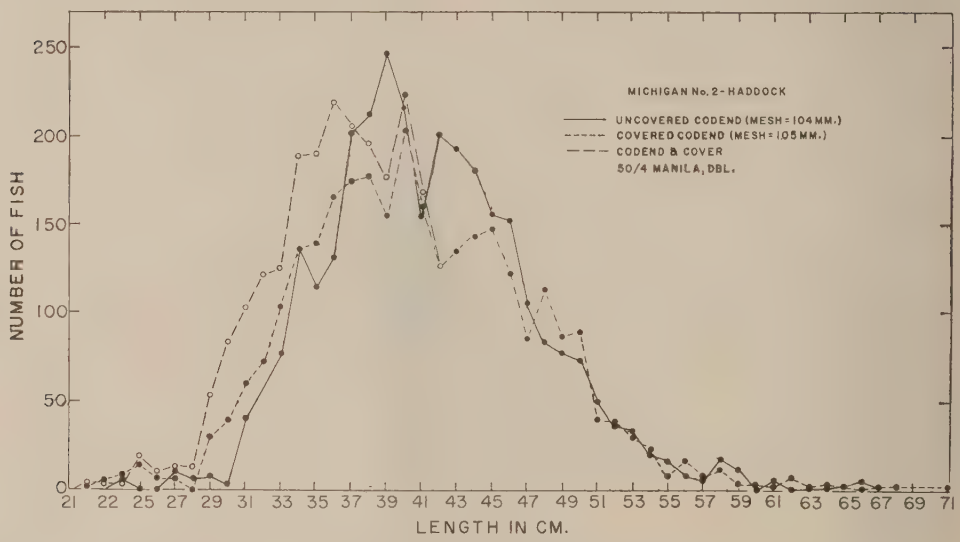
MICHIGAN No. 2 - HADDOCK
UNCOVERED CODEND (MESH = 104 MM.)
COVERED CODEND (MESH = 105 MM.)
CODEND & COVER
50/4 MANILA, DBL.
NUMBER OF FISH
LENGTH IN CM.
0
50
100
150
200
250
21 22 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71

Fig. 15. *Michigan II* catches with covered and uncovered codends.

The numbers of fish of each length caught by the two codends are given in Table F-17. Length frequencies of the catches are plotted in Figure 15. The length frequency curves are less regular than in the *Michigan* No. 1 series, because just half as many fish were caught. Again, nearly the same numbers of fish were caught by the two codends. The mean length was slightly lower in the covered codend (41.0 cm) than in the uncovered codend (41.6 cm). Within the effective selection range (*i.e.*, less than 41 cm) the covered codend caught slightly more fish (1,450) than the uncovered codend (1,430). The mean sizes of fish within the selection ranges were 35.9 cm for the covered codend and 36.7 cm for the uncovered codend.

Thus our analysis demonstrates that somewhat more fish of a smaller average size were taken within the selection range by the covered codend. The slight difference of 1 mm in the mesh size could not be expected to cause this. The differences could very well have come about through random variation in catches. If we assume, however, that the difference is real and the catches in the uncovered codend best represent the retained portion of the catch, a recomputed 50% point for this series of tows can be calculated which is approximately 3.5 cm higher (from 29.5* to 32.5 cm*).

This adjusted 50% point agrees well with that of 32.3 cm* obtained for the whole series of tows with the covered codend (14 tows - see p. 67). We may conclude from this that escapement from the covered net for the 5 tows which were paired was artificially low. This effect must not have extended to the whole series of covered tows made on this cruise because the final 50% point determined from the series of 14

tows and the adjusted 50% point for the 5 replicate tows show good agreement.

The small number of fish caught in the lower part of the selection range of the codends again restricts the applicability of results.

Albatross III No. 51 - Haddock: Two series of replicate tows, one of 5 and one of 9 pairs, were completed on Cruise No. 51 of the *Albatross III* in June of 1953, with the following results:

Series I

Codend	Towing Time Hrs. – Min.	Mesh Specifications Size (mm)	Type	Number of fish in: c.e.	cov.	50% Point (cm)
Covered	5 – –	76	75/4 manila	7121	2733	24.5*
Uncovered	5 – –	75	double	8982	–	–

Series II

Codend	Towing Time Hrs. – Min.	Mesh Specifications Size (mm)	Type	Number of fish in: c.e.	cov.	50% Point (cm)
Covered	9 – –	76	75/4 manila	8248	4337	24.5*
Uncovered	9 – –	75	double	10906	–	–

The same covered codend was used throughout, but different uncovered codends were used for Series I and Series II. The mean mesh sizes for the two uncovered codends were identical, however. The data for the two series are given in Table F-18; the results of the two series are quite similar. Because of this, and the fact that the mesh sizes of the two uncovered codends are the same, we have combined the results and will consider both series together. The results are plotted in Figure 16.

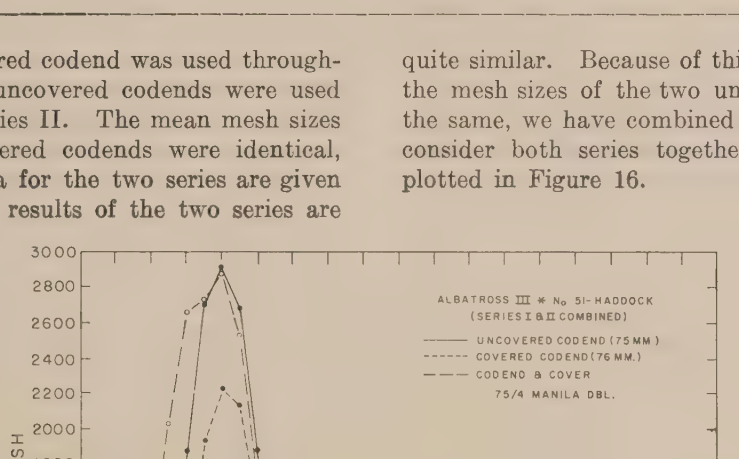

Fig. 16. *Albatross III* No. 51 catches with covered and uncovered codends.

Upon examining the length frequencies we see that more, rather than less, of the fish within the effective selection range (*i.e.*, less than 31 cm) have been caught by the uncovered codend. We observe also that there are more fish above the selection range in the uncovered codend and may propose that the net without the cover is operating more efficiently for *all* sizes than the covered net. We can test this hypothesis by comparing the total number of fish of 31 cm and over in the two nets. The catches in this category are 3,769 for the covered codend and 4,212 for the uncovered codend, a difference of 443 fish representing 12% of the covered codend catch. But below 31 cm the uncovered codend caught 35% more fish than the covered codend. If we adjust the uncovered codend catch of sizes less than 31 cm by the 12% it still remains 23% above the covered codend catch. We therefore cannot conclude that the higher catches by the uncovered codend of fish in the selection range were due to greater overall efficiency.

Another possibility is that the uncovered net actually operated with about 23% greater efficiency for fish within the selection range only. A possible explanation of this is offered by results obtained in another set of experiments (p.00) which indicated that a high proportion (ca. 50%) of haddock between 20 and 30 cm escaped through the forward parts (mesh of about 120 mm) of the trawl used on the *Albatross III*. All fish of over 47 cm were shown to be retained by the forward parts of the trawl. If the effect of the cover were such as to enable these fish to escape more easily through the forward parts of the trawl we could expect to catch fewer in the covered codend.

This hypothesis, however, does not assist us in detemining if the cover has a masking effect. We can, however, propose that if a masking effect were operating, the excess of the uncovered codend catch over the covered codend catch at each size would be related to the proporton of fish of that size which escape. Thus, as the escapement increases, per size interval, the excess of the uncovered over the covered codend should decrease. The approximate percentages of fish which escape at each size and the percentage excess of the uncovered over the covered codend catches are shown below for the sizes between 21 and 30 cm:

Length (cm)	21	22	23	24	25	26	27	28	29	30
% Escapement	79	72	62	50	38	25	15	7	5	4
% Excess	52	54	47	45	40	31	26	23	29	49

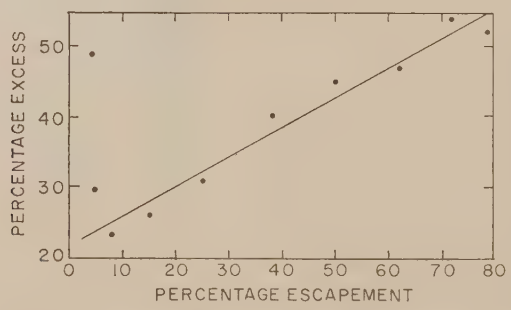

Fig. 17. Percentage escapement and percentage excess of uncovered over covered codend in *Albatross III* No. 51 results.

The relationship, which is plotted in Figure 17, shows that our hypothesis is not supported, and no masking effect can be demonstrated. Thus, the cover has not been shown to reduce escapement and in fact, if anything, has seemed to improve it.

Albatross III No. 52 - Haddock. Ten pairs of alternate tows were completed on Cruise No. 52 n July 1953, with results as follows:

Codends	Towing Time Hrs. – Min.	Mesh Specifications Size (mm)	Type	Number of fish in: c.e.	cov.	50% Point (cm)
Covered	12 – 50	113	45/4 manila	2977	2455	36.8*
Uncovered	11 – 50	114	double	3555	–	–

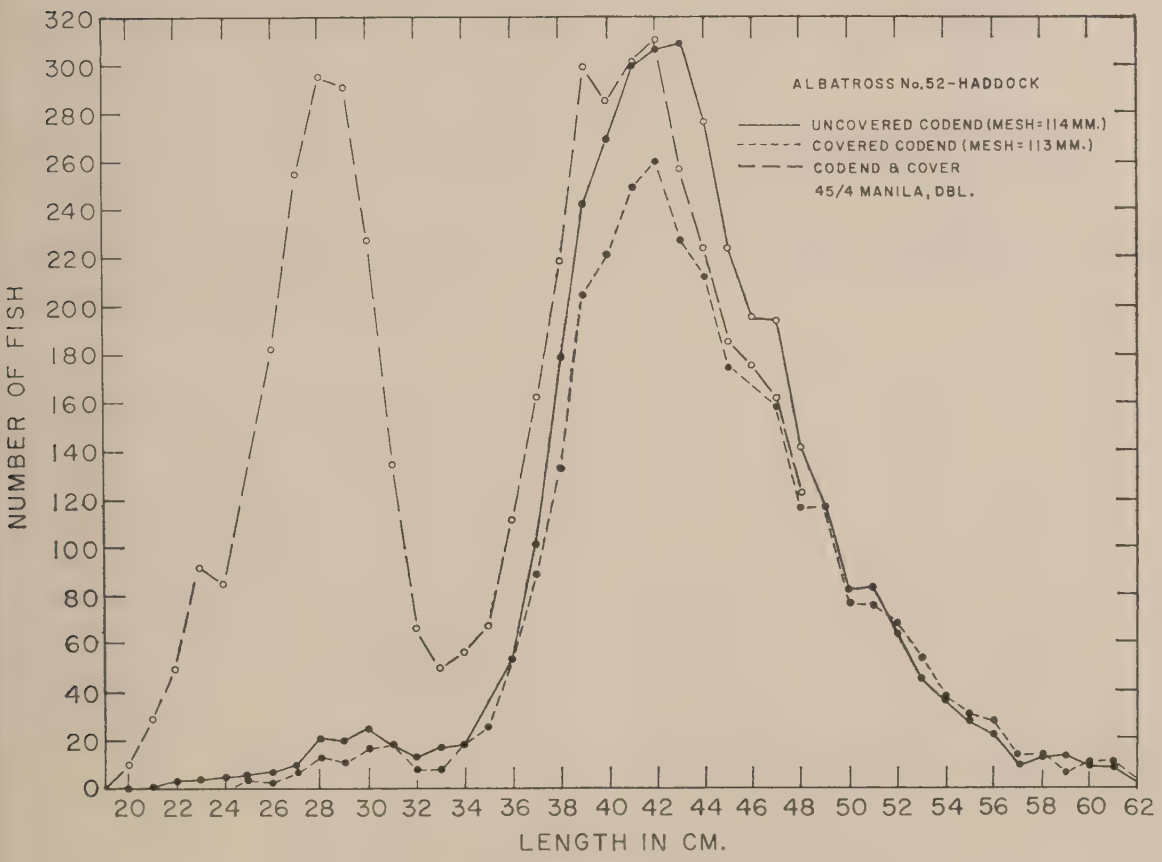

Fig. 18. *Albatross III* No. 52 catches with covered and uncovered codends.

The numbers of fish of each length caught by the two codends are given in Table F-19. Length frequencies of the catches plotted in Figure 18 show the great amount of escapement of small sizes of haddock in this experiment. The small number of 20-33 cm fish remaining in the covered codend do not exceed the number of these sizes remaining in the uncovered codend. Although this condition is particularly well demonstrated at the smaller sizes it exists generally throughout the selection range of the codend. The numbers of fish caught by the two codends are nearly identical from 49 cm on, being 561 for the uncovered codend and 570 for the covered codend.

This experiment yields results similar to those of the *Albatross III* No. 51 experiments in respect to the excess of the uncovered codend catch over the covered codend catch within the escape sizes. The difference in towing time (about 8%) could partially account for this difference, but we would then have to accept a lowered relative efficiency for sizes over 49 cm by the uncovered codend.

The percentage escapement from the codend and the percentage excess of the covered over the uncovered codend within the selection range are shown below:

Length (cm)	25	26	27	28	29	30	31	32	33	34	35	36
% Escapement	98	97	97	96	95	93	89	85	80	71	62	52
% Excess	25	133	43	61	82	47	6	62	113	—	40	4

Length (cm)	38	39	40	41	42	43	44	45	46	47	48
% Escapement	38	30	24	19	15	11	8	6	4	3	1
% Excess	35	18	22	20	18	37	30	28	16	22	21

These data are plotted in Figure 19.

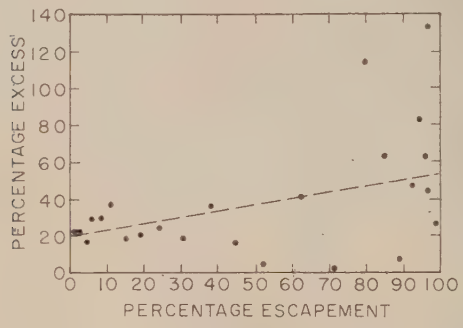

Fig. 19. Percentage escapement and percentage excess of uncovered over covered codend for *Albatross III* No. 52.

Again we see no sign of decrease in excess of uncovered over covered codend catch, even with the increase in escapement. We may conclude, therefore, that the cover did not reduce the escapement of haddock from the codend in this series of tows.

Pairtows I - Haddock: Operation Pairtows I was a joint operation of the *Albatross III* and the *Delaware* in October 1955. The vessels were rigged with identical nets. Initial tests showed that they caught nearly equal proportions of sizes of fish within the effective selection ranges of the codends to be tested (*see* p. 38). We then made two series of paired tows with covered codends on one vessel's net and uncovered codends on the other's, the vessels fishing as near to each other as possible and setting and hauling back at nearly the same time. Series I consisted of 5 pairs of tows with cotton codends. Results were as follows:

Codends	Towing Time Hrs. – Min.	Mesh Specifications Size (mm)	Type	Number of fish in: c.e.	cov.	50% Point (cm)
Covered	5 – 50	138	120th cotton	305	2299	49.6*
Uncovered	5 – 57	144	single	73	–	–

The data are given in Table F-20 The length frequencies are plotted in Figure 20. Any analysis of the catches of the two codends would show them to be greatly dissimilar, with the covered codend having many more fish of a smaller size than the uncovered codend, and we must conclude that the cover is indeed exerting a masking effect. We see from the great escapement of fish, however, that this effect is of little consequence for the smaller sizes of fish. The apparent masking has a much more important effect upon the larger sizes (*i.e.*, 43 cm and above)

where considerably fewer fish are escaping. Why the larger sizes of fish should be more affected by the cover than the smaller sizes of fish is difficult to explain. One possibility is the larger mesh size of the uncovered codend. The effect, of course, could be owing to chance variation.

A singular demonstration of the effectiveness of the cover was provided by an "unpaired" tow which followed immediately the conclusion of the above series. In this tow, 1,087 haddock were caught in the cover and none in the codend; all had escaped. The sizes ranged from 20 to 46 cm (Pairtows, Tow No. 42 of *Delaware*). The gear was apparently operating properly and conditions were, as nearly as can be determined, much the same as on the previous 5 tows of this net reported above.

Pairtows I, Series II, consists of 3 pairs of replicate tows with braided nylon cargo netting (43 yards/pound). Results are as follows:

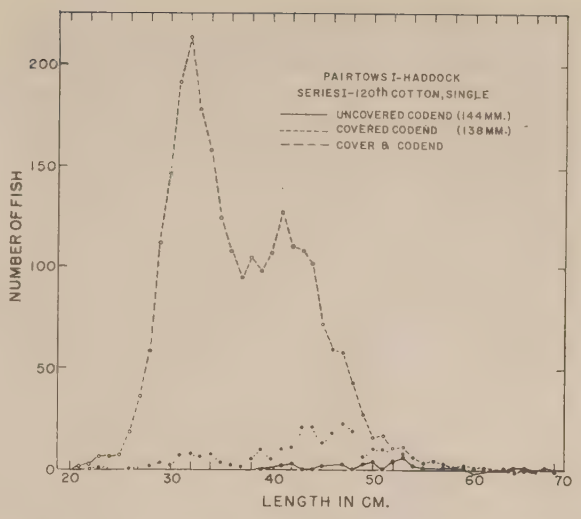

Fig. 20. Pairtows I, Series I. Catches with covered and uncovered codends.

Codend	Towing Time Hrs.	Towing Time Min.	Mesh Specifications Size (mm)	Mesh Specifications Type	Number of fish in: c.e.	Number of fish in: cov.	50% Point (cm)
Covered	3	0	135	Braided nylon	215	1167	44.6*
Uncovered	3	8	128	43 yds/lb single	50	—	—

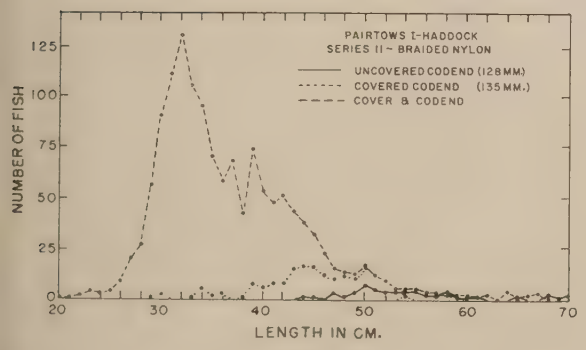

Fig. 21. Pairtows I, Series II. Catches with covered and uncovered codends.

The data are given in Table F-21. The length frequencies are plotted in Figure 21. The results are similar to those obtained in Series I. The smaller catches of the uncovered codend cannot be explained on the basis of mesh size in this instance as the uncovered codend mesh was 7 mm smaller than the covered codend mesh.

We should draw conclusions from these two experiments with caution because of the few tows involved. The case is strengthened by the similarity of results of the two series, however, particularly since the *Delaware's* codend was covered in one series, the *Albatross III's* in the other, thus eliminating the possibility of bias caused by differential selection characteristics of different nets.

Considering the results of Series I and II, we can draw certain inferences: with codends of the sizes tested, masking caused by the cover is unimportant for lengths of 40 cm and smaller. Beyond that size more serious consequences can result, particularly because the 50% point, which is of great usefulness, could be estimated several cm too low.

Priscilla V - Silver Hake: Three series of replicate tow experiments were carried out aboard the *Priscilla V*. The *Priscilla V* is a wooden otter trawler of the size that normally fishes for silver hake. Her net was a cotton trawl rigged to conform as nearly as possible to average characteristics of the diverse types used in the fishery (*see* p. 28 for specifications).

Four pairs of replicate tows with cotton codends were completed in Series I with the following results:

Codend	Towing Time Hrs.	Min.	Mesh Specifications Size (mm)	Type	Number of fish in: c.e.	cov.	50% Point (cm)
Covered	3	35	73	96th cotton	4515	1433	19.9*
Uncovered	3	50	72	single	3341	—	—

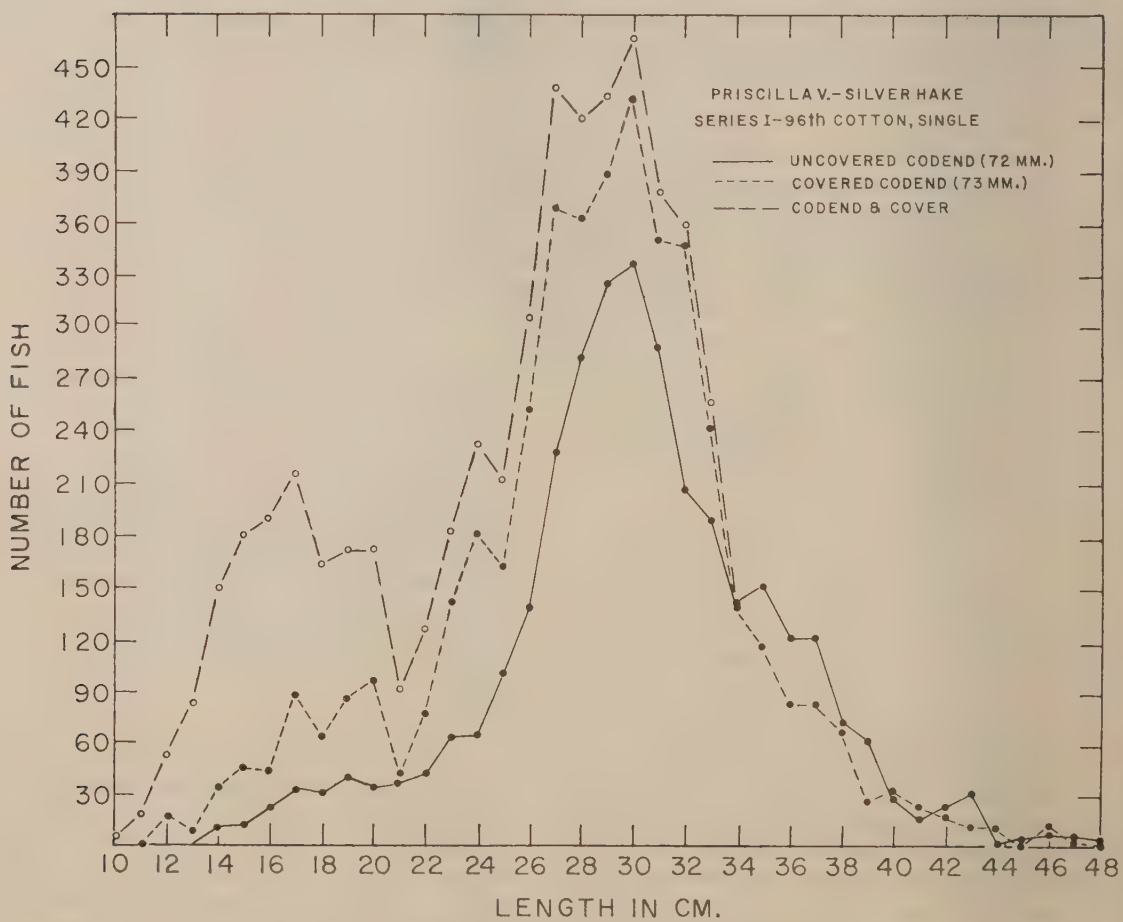

Fig. 22. *Priscilla V* catches with covered and uncovered codends, Series I.

The data are given in Table F-22 and plotted in Figure 22. The greater "retention" of the escape sizes of silver hake indicates that the cover is exerting a serious masking effect.

We commenced to make various adjustments to the gear in order to eliminate the observed masking effect. Divers, who examined the rig while towing slowly in shallow water, reported that the cover was constricted by the splitting strap and appeared to have too little slack. The splitting strap was adjusted and the cover enlarged before Series I tows were begun. Additional observation by divers during the Series showed that the adjustments had improved the action of the cover somewhat, but the cover was still not flowing clear of the codend. We then added floats to the upper side of the cover and its operation was further improved. However, the covered codend was still retaining more of the escape sizes, and work with it was discontinued.

Upon completion of Series I tows, the cotton codends were exchanged for nylon codends and the study continued with Series II. Four pairs of tows were completed in Series II with the following results.

Codend	Towing Time Hrs.	Min.	Mesh Specifications Size (mm)	Type	Number of fish in: c.e.	cov.	50% Point (cm)
Covered	4	55	85	400/3, nylon	2896	2626	29.8*
Uncovered	4	55	84	twisted, single	1898	—	—

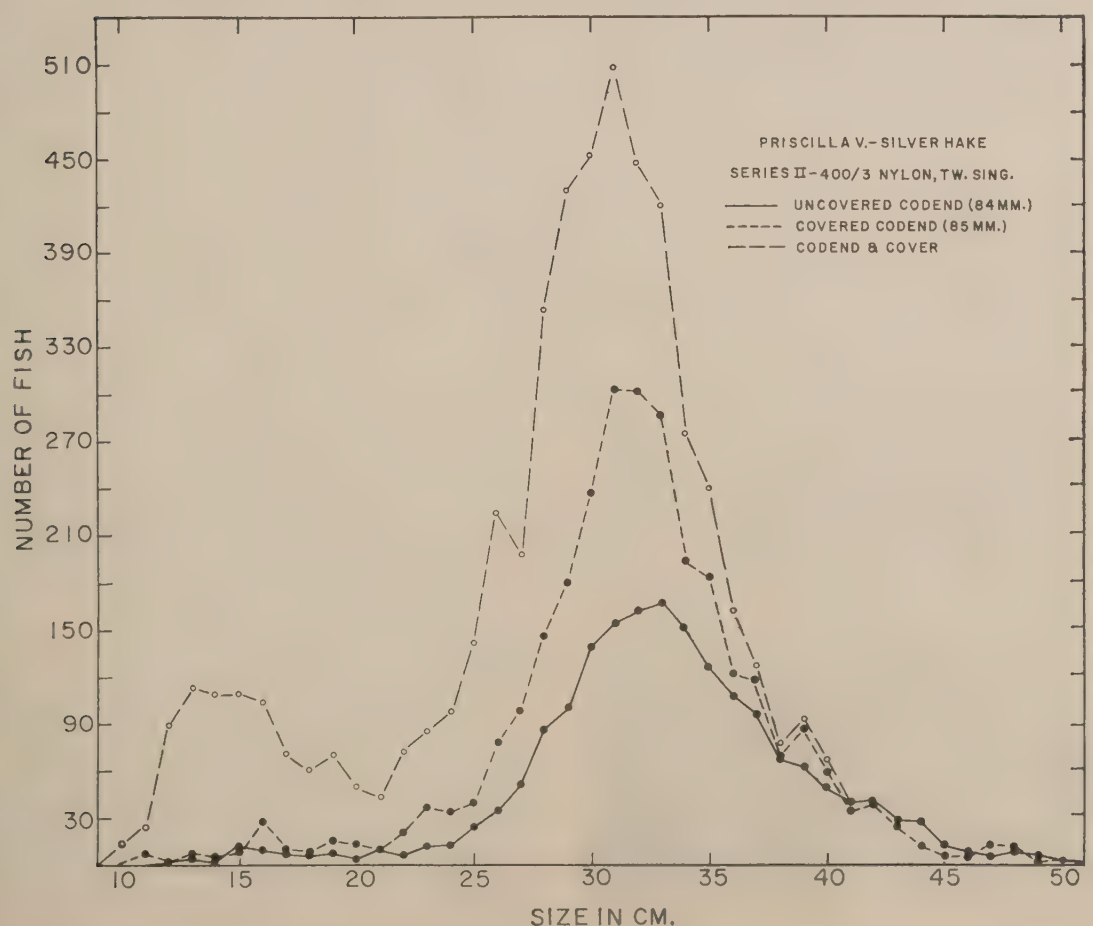

Fig. 23. *Priscilla V* catches with covered and uncovered codends, Series II.

The data are given in Table F-23 and plotted in Figure 23. A masking effect of the cover is again evident. At this point in the operations the nets were completely overhauled for various reasons. One major change involved rehanging the nets to the foot ropes and headlines, the lengths of which were altered. Another major change was the removal of a cover which had extended over the whole area of the upper belly. We then commenced Series III with the same codends and 9 pairs of tows were completed with the following results:

Codend	Towing Time Hrs.	Towing Time Min.	Mesh Specifications Size (mm)	Mesh Specifications Type	Number of fish in: c.e.	Number of fish in: cov.	50% Point (cm)
Covered	8	50	82	400/3, nylon	3570	1214	27.7*
Uncovered	8	45	82	twisted, single	3700	—	—

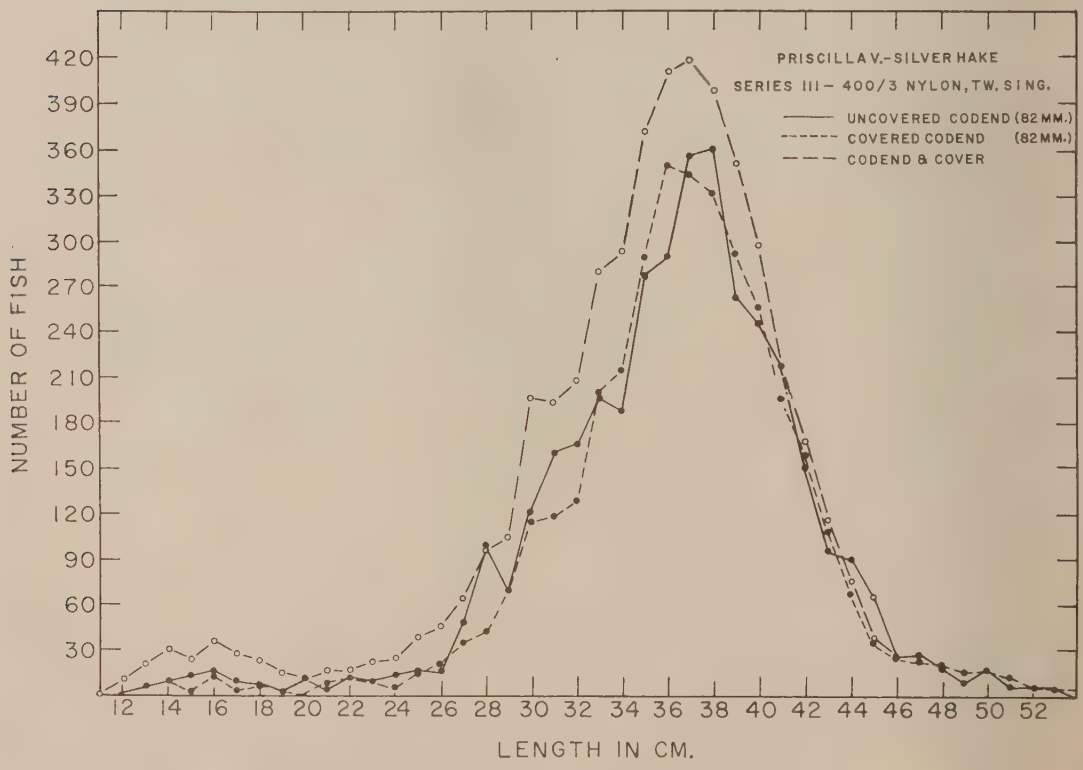

Fig. 24. *Priscilla V* catches with covered and uncovered codends, Series III.

The data are given in Table F-24 and plotted in Figure 24. Although the escape sizes of silver hake were scarce in this series, a sufficient number were taken to show that the masking effect was no longer pronounced. The rehanging and removal of the belly cover had apparently in some inexplicable way improved the operation of the gear.

We are, however, not able to explain easily why the 50% point should be lower in Series III than in II. This is partially explained by the shrinkage of the covered codend from 85 to 82 mm but the selection factor remained higher for Series II (3.5) than for III (3.4). Throughout much of the *Priscilla V* work, escapement of silver hake was much lower than would be ex-

pected from comparison with other species and from European results with *Merluccius*. The operation of many unknown factors could increase the escapement considerably, just as fear stimulated by a shark in the codend did on one occasion (*see* p. 61). During Series III we operated at a different time, in somewhat deeper water (23 rather than 19 fm.), and on different grounds within the same general area. Catches were lower and a greatly different size composition was encountered. Also the modification to the gear could have somehow lowered the escapement even while lessening the masking effect of the cover.

We may conclude, nevertheless, that the covered codend results obtained for Series III and subsequent operations were not seriously affected by masking of the cover, and, albeit somewhat less safely, that the modifications to the gear somehow improved the operation of the cover.

We may propose that the uncovered codends in Series I and II give a better representation of the "actual" retention than the covered codends. If the percentages retained are recalculated on the basis of the uncovered codend catches, the 50% points will be about 3 cm higher. The apparent masking effect has thus reduced the 50% point by 3 cm for both series. Selection factors are similarly reduced by about 0.4. These differences point up the necessity of conducting tests on the operation of covers before proceeding with selection experiments.

Albatross No. 64 - Redfish: The final series of covered and uncovered codend tows to be presented is that of Cruise No. 64 of the *Albatross III* in August 1953. The first part of this redfish selection cruise was devoted to studying the effect of the cover. We experienced great difficulty in obtaining a good series of replicate tows with and without covers because of the sporadic changes in abundance of fish and because the steep contours of the grounds worked caused difficulty in controlling the depth of tow. Nevertheless, a series of 6 pairs of tows was completed which can be examined with the reservations mentioned. The results are as follows:

Codend	Towing Time Hrs.	Towing Time Min.	Mesh Specifications Size (mm)	Mesh Specifications Type	Number of fish in: c.e.	Number of fish in: cov.	50% Point (cm)
Covered	5	45	109	45/4, manila	3417	1916	23.6*
Uncovered	5	37	110	double	3287	—	—

The data are given in Table F-25 and plotted in Figure 25. The figure shows that the covered codend retained no more redfish throughout the important part of the selection range than the uncovered codend. The reverse is shown to be true in the vicinity of the 50% point. No explanation can be given for this except that it may be owing to random variability caused by difficulties in controlling the paired tows. At all events, we can see no evidence in these results that the cover exerted a masking effect.

Discussion

No single conclusion can be supported by all these studies as to whether the covered codend technique is valid. In many instances no effect of the cover can be demonstrated. In some instances definite reduction in escapement is shown, while in others the reverse seems true. In one instance, modification of the gear appeared to eliminate the masking effect. We are led to conclude from our study, however, that properly controlled covered net experiments will give valid results.

The final proof, of course, is in the application of the experimental results to the management of a fishery. We have shown elsewhere (p. 88) that the selection of haddock in the Georges Bank fishery by ICNAF recommended $4\frac{1}{2}$ inch codends agrees almost exactly with our covered codend experimental results. This fact provides the most significant confirmation of our haddock selection results.

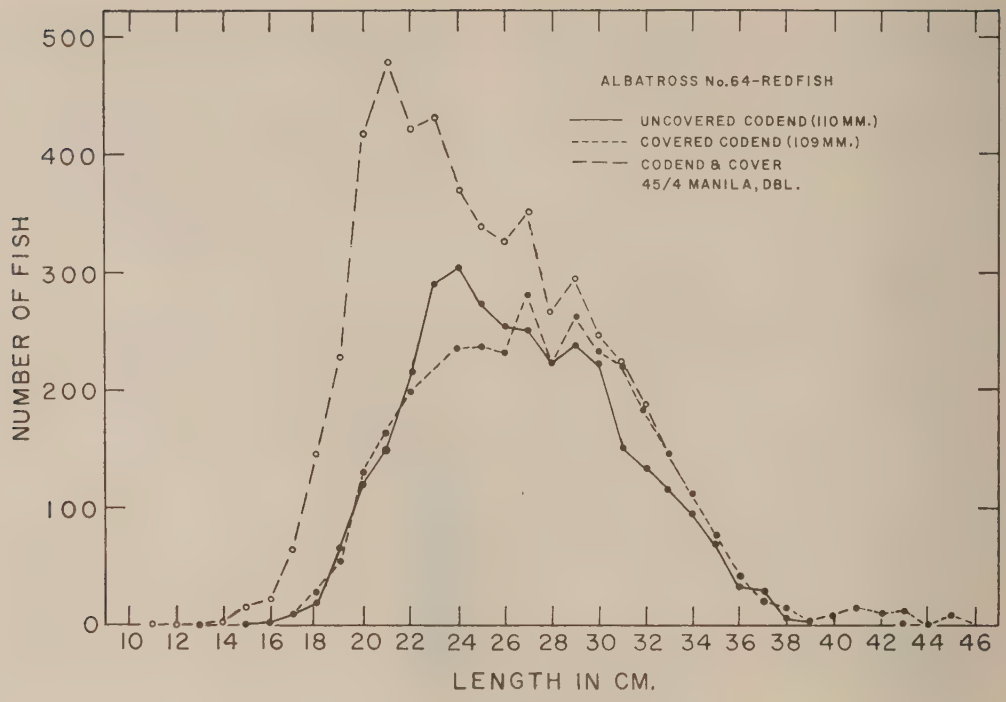

Fig. 25. *Albatross III*. No. 64 catches with covered and uncovered codends.

D. EFFECT OF DURATION OF TOW ON CODEND ESCAPEMENT

Abstract

The results of three series of tows of varying duration are analyzed. It is shown that the selection factor is closely related to tow duration, with longer tows yielding substantially higher escapement.

Methods

Variation in tow length is one of the factors which many workers consider important in determining codend escapement. Previous experimental evidence has not been conclusive. Gulland (1956), for example, found insufficient evidence in a study of tows of 1/2 hour to 3 hours to show that the duration of tow had an effect upon the amount of escapement. The three lowest 50% points obtained, however, were all for tows of shortest duration.

Investigating the effect of duration of tow was the primary objective of Cruise No. 49 of the *Albatross III*. The standard net and cover rig (p. 29) were employed throughout the experiment. Three series of tows of varying duration (20, 40, 60, and 80 minutes) were conducted in alternating sequence.

Results

Series I consisted of 3 tows each of 20, 40, 60, and 80 minutes duration. The codend was double manila 50/4 of 113 mm mesh size. The data (length measurements of haddock) are given in Table F-26 and selection curves for each tow duration are shown in Figure 26. The 50% point advanced regularly with increasing length of tow (33.8*, 35.2*, 37.3*, and 38.6* cm). The selection factor increased from 3.0 for 20 minute

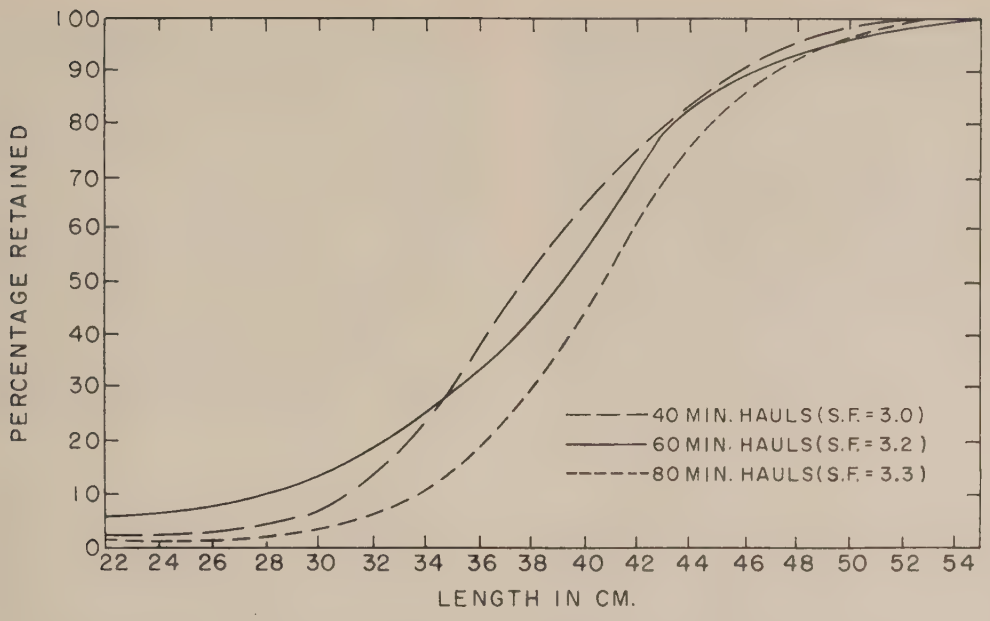

Fig. 26. Selection curves for 20, 40, 60, and 80 minute tows with a 113 mm mesh codend of 50/4 manila, double.

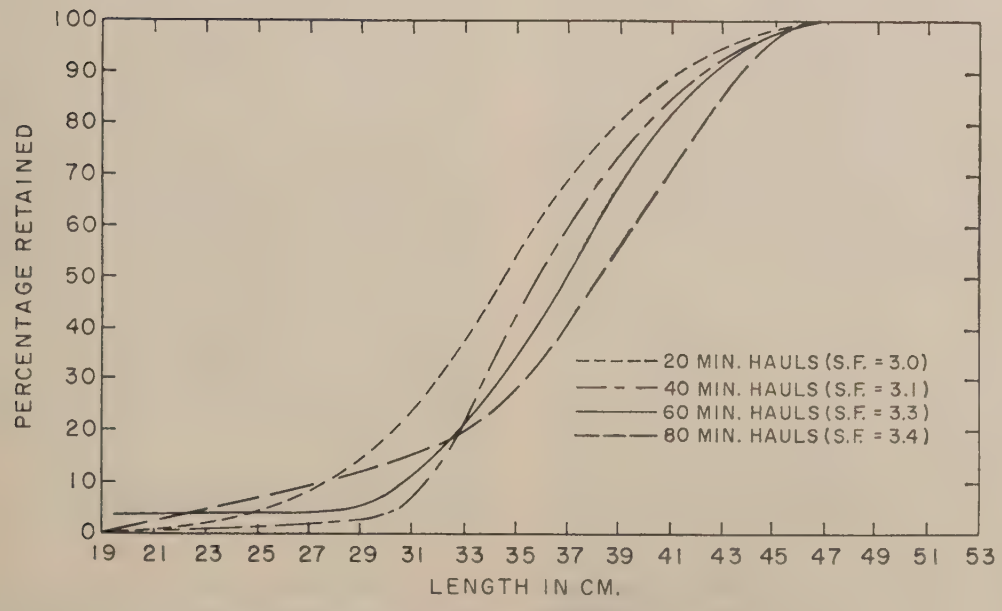

Fig. 27. Selection curves for 40, 60, and 80 minute tows with a 123 mm mesh codend of 45/4 manila, double.

tows to 3.4 for 80 minute tows. Slight anomalies appear at the lower ends of the curves; these are not important enough to affect the general conclusions.

Series II consisted of 8 tows each of 40 and 80 minute duration and 7 tows of 60 minute duration. The codend was double manila 45/4 of 123 mm mesh size. The data are given in Table F-27, and the selection curves for each tow duration are shown in Figure 27. The 50% points advanced regularly with increasing length of tow (36.8*, 39.7*, 41.2* cm). The selection factor increased from 3.0 for 40 minute tows to 3.3 for 80 minute tows. The 60 minute group shows a lower escapement below the 30% escapement point, however, than the 40 minute group.

Series III consisted of 4 tows each of 40 and 60 minutes duration and 5 tows of 80 minutes duration. The codend was double manila 75/4 of 73 mm mesh. The data are given in Table 3, F-28, and the selection curves for each tow duration are shown in Figure 28. The 50% point is shown to advance from 24.8* for the 40 minute tows to 25.2* for 60 minute tows but then decreases to 24.8* cm for 80 minute tows. The shapes of the curves are shown to differ somewhat among the three towing durations. The escapement for 80 minute tows is shown to be higher than for the other two durations up to about the 35% point and from the 70% nearly to the 100% point. Although the dampened escapement in the middle of the selection range has reduced the selection factor for the 80 minute tows, the general result is not greatly different from that of Series I or II.

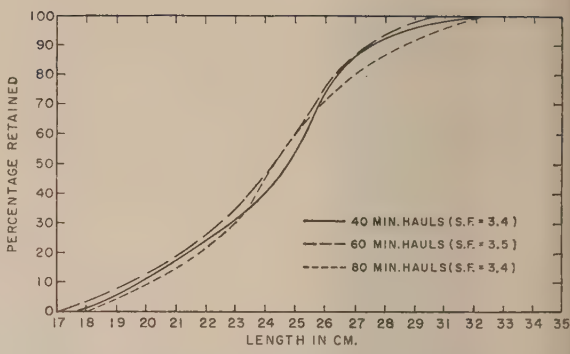

Fig. 28. Selection curves for 40, 60, and 80 minute tows with a 73 mm mesh codend of 75/4 manila, double.

Tows made without hides on the lower side of the codend were incorporated into Series II and III. We have shown previously that no demonstrable effect was produced upon escapement by removing hides (p. 35). We are assured, therefore, that this study was not influenced by combining the tows with and without hides.

We may thus conclude that, within the range of towing times studied, greater escapement is effected by lengthening the duration of tow.

Discussion

It may be argued that the increase in selection factor could have come about simply through associated increase in catch size and is not actually related to tow duration. We have, therefore, summarized below the average numbers of haddock in the codend and the selection factors for all series:

Tow Duration	Series I Numbers of Fish	Series I S.F.	Series II Numbers of Fish	Series II S.F.	Series III Numbers of Fish	Series III S.F.
20	96	3.0	—	—	—	—
40	150	3.1	475	3.0	134	3.4
60	161	3.3	492	3.2	199	3.5
80	128	3.4	880	3.3	175	3.4

As one might expect, the longer tows (which yielded the higher selection factors) generally produced the greater catches. Closer examination of the results for each series, however, indicates that the correlation between selection factor and number of fish caught is quite imperfect. Our analysis of the catch size - selection factor relation for tows of equal duration (p. 71)

suggests that increased catches should lower the selection factor. Thus we are led to the conclusion that the increasing catches should have a contrary effect; *i.e.*, to actually dampen the effect of increasing tow duration on selection factor.

The effect of duration of tow was greatest for the 123 mm and least for the 73 mm codend. As shown also by our studies of other variables, the greatest consistency in results is found among the smaller mesh sizes. As the influence of variables, such as duration of tow, is greatest with large mesh sizes, we must be most critical of the results obtained from trials with larger meshes.

The 80-minute duration approximates most nearly the length of tow by our Georges Bank fleet of large (150 tons and over) otter trawlers. Our medium otter trawlers (50-149 tons), however, usually tow for two hours during the day and for three hours at night. Tows of one hour or less are not usual to any of our trawlers. Since the effect of tow length in applying selection results can be important, the range of towing times in experimental work should be extended to the maximum expected for important segments of the fishery when possible.

E. ESCAPEMENT OF HADDOCK AND SILVER HAKE THROUGH WIRE MESHES

Abstract

The effect of variation in mesh size upon selection was investigated through use of a codend made partially of wire meshes. The selection of the experimental wire mesh codend did not prove to be sharper than manila. Total escapement through the wire mesh codend was shown to be lower for haddock than through a manila mesh codend of equivalent size. The data for silver hake are indicative of the same results but do not appear reliable enough to permit definite conclusions.

Introduction

It has been suggested by McCracken (this publication no. 12) and others that the relative sharpness of selective action may be determined, at least in part, by the uniformity of mesh size. It seems logical that a lack of uniformity would tend to dull the selective action of a codend. The size of meshes of codends, particularly those of hand-braided manila, may vary as much as 30% of the mean size. Since the selection range of any particular mesh size is normally about 30% of the 50% retention length, there is a suggestion that variation in mesh size may be significant in determining the selection range.

To investigate the importance of uniformity of mesh size and shape in escapement, we substituted a piece of heavy wire mesh into the escapement area of a standard codend. It was hypothesized that the uniformity of mesh size in the wire panel would have the affect of sharpening the selective action of the codend, providing that lack of flexibility and the unvarying mesh "shape" (mesh angle of 90°) among other inherent characteristics of this gear, were not important factors in the escapement of fish.

Methods and Gear

Because a codend made entirely of wire mesh would be difficult if not impossible to handle we used only a partial section of wire mesh in place of the manila twine in the upper, rear part of the codend through which the most of the escapement takes place (p. 31). The wire mesh section, which was 8 feet long, extended from the center rearward to within 4 feet of the end of the codend and extended transversely from laceage to laceage as shown in Figure 29.

A cover was rigged in the standard manner (*see* p. 29) over the whole upper side of the codend, covering both manila and wire mesh. A number of standard round floats were attached to provide the buoyancy needed to offset the weight of the wire. A diagrammatic sketch of the completed rig is shown in Figure 30. A close-up view of the wire mesh, the normal twine mesh of the codend, the cover mesh, and the method of attachment is shown in Figure 31. The manila sections were made of small mesh (57 mm) to prevent fish from escaping through

Fig. 29. Top view of the wire mesh codend before attachment of cover.

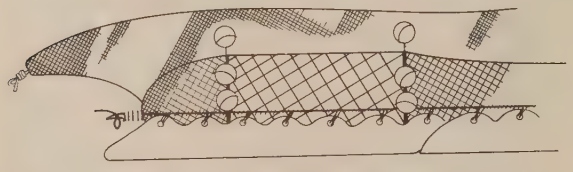

Fig. 30. The completed wire mesh codend.

Fig. 31. Detail of wire mesh codend construction.

them rather than the wire mesh. Because of their rigidity, the wire meshes cannot be extended and measured directly as can twine meshes. A dimension of the wire mesh equivalent to that of twine mesh can be estimated by doubling the average dimension of the bar measurement, however. A twine mesh equivalent size of 100 mm thus may be estimated from the bar measurement of 50 mm.

Results

Two tows of one hour duration were made with the wire mesh codend yielding a total catch of 817 haddock and 2,358 silver hake. The numbers caught by cover and codend and the calculated percentages retained are given in Tables F-29 and F-30. The selection curves for the two species are plotted as the solid lines in Figures 32 and 33.

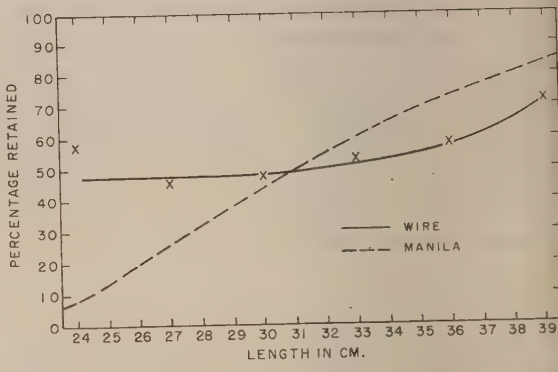

Fig. 32. Silver hake selection curve for wire mesh an manila mesh codends.

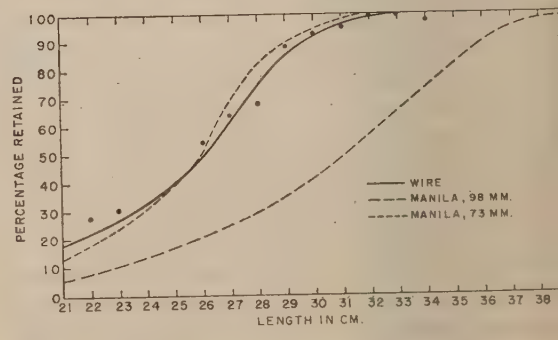

Fig. 33. Haddock selection curve for wire mesh ar manila mesh codends.

The silver hake data suggest that the gear exercised little selective action, but this was not surprising in view of our results from other experiments. Silver hake do not appear to have a strong escape reaction to a codend and also seem to be significantly affected by the degree of flexibility of the twines (*see* pp. 63 and 83). The dashed line in Figure 4 represents the selection curve for a 100 mm manila mesh estimated from results of previous experiments (p. 82). The wire mesh selection curve is certainly duller, with only a hint of selective action towards the large sizes of fish and escapement appeared to be almost entirely random with respect to length.

The haddock selection curve for a manila codend of a mesh size (98 mm) comparable to the wire mesh is also plotted in Figure 5 from *Michigan*, Ser. II, p. 67.

The 50% point for the wire mesh is shown to be much lower, but its selective action appears to be sharper since the curve is steeper. Since the steepness of a codend selection curve is a function of the length of fish at 50% escapement, it is necessary, for proper comparison, to use the selection curve for a manila codend having the same 50% point as the wire mesh. Such a curve is available for a 73 mm double manila codend (from *Albatross III*, Cruise 49, Ser. III, 60 min. tows - see p. 69), and has been entered as the dotted line in Figure 5. Comparison of this curve with the wire mesh curve shows the manila to have the sharper selection.

The conclusion must be drawn from these comparisons that wire mesh yields selection no sharper than manila mesh, and if anything, yields duller selection.

Discussion

The results of this study do not confirm that sharpness of selection is correlated primarily with range in mesh size, as the wire netting, of a constant size throughout, yielded selection that was duller than manila. The special gear developed for this study, however, differs from the normal codend in many ways.

The fact that escapement of haddock appears to be generally lower for wire meshes than for equivalent size manila meshes can possibly be explained by the fact that the wire mesh only covered an area of 8 feet of the top of the codend and terminated 4 feet from its terminus. The manila meshes - of which the remainder of the upper side was constructed - were of a size so small (57 mm) as to prevent the escapement of haddock larger than about 20 cm. All the fish which are larger than this size must have escaped through the wire mesh. As the effective escape area of the codend is near the end of the upper side, we can conclude that the fish which were prevented from escaping by the small manila meshes have been so prevented primarily in the last 4 feet of the codend, rather than in the parts forward of the wire mesh.

We are concerned primarily with the sharpness of selection rather than the total amount, and therefore with the shape of the curve rather than the position. We can assume that fish which were prevented from escaping were of an average distribution of sizes and any effect would apply equally to all sizes. The shape of the selection curve, therefore, might not be altered by the fact that only a part of the upper side of the codend was made of wire mesh.

Our experimental results also relate to another factor of importance: that of the effect of the "extensibility coefficient" of the material used in codends. This matter has been investigated by von Brandt (p. 18) who discovered a relationship between the factor expressing elasticity of the fiber and the amount of escapement from the meshes. We may thus expect the wire mesh, which has no extensibility, to yield a much lower escapement than the manila mesh. This is confirmed by the haddock results but not by the silver hake results. The poor selectivity for silver hake cannot be easily explained and may be due to some flaw in the experimental method. We must, therefore, draw conclusions from the silver hake data with caution.

The rigidity of the wire itself may affect the selection as well as indeterminate factors in its rigging which might have caused abnormalities in escapement. We must, however, conclude that there are factors other than range in mesh size which may affect the sharpness of selection of codends.

F. ESCAPE RESPONSE IN MESH SELECTION

Abstract

The effect of escape response motivation on escapement through meshes is considered with particular reference to silver hake. An index, escape-response index, is developed to relate potential and actual escape for various species. An example is given of the effect of increased escape response due to the presence of a shark in the codend.

Introduction

Many workers have investigated physical and mechanical factors in attempting to explain certain features of mesh selection results. Relationships have been developed between such factors as girth of fish, opening of mesh, flexibility and tension of twine, and angles of approach incidence of fish to netting. These studies have not, however, considered psychological factors. So little is known about behavioral patterns of marine fish that it is not surprising that escapement through the meshes of a net is regarded as a more or less random, undirected process. It is the purpose of this paper to demonstrate the importance of response to stimulii in escapement, and to show how it varies with species and conditions of capture and how it may be measured.

Relation of Selection Factor to Girth Factor

It has been proposed by many workers that the selection factor of a species should be related to, and even predictable from, the girth. In general, this has been shown to be true although some anomalies may be found. Figure 34 shows the relation between selection factor and girth expressed in terms of the *girth factor* (G.F. = girth/length) for four representative species for which we have experimental results: yellowtail flounder (*Limanda ferruginea*), redfish (*Sebastes marinus*), silver hake (*Merluccius bilinearis*), and haddock (*Melanogrammus aeglefinus*). The selection factors shown represent average escapement from various kinds of nets under various conditions. We have fitted a line to the data for yellowtail, redfish, and haddock to permit comparison with silver hake. The selection factor

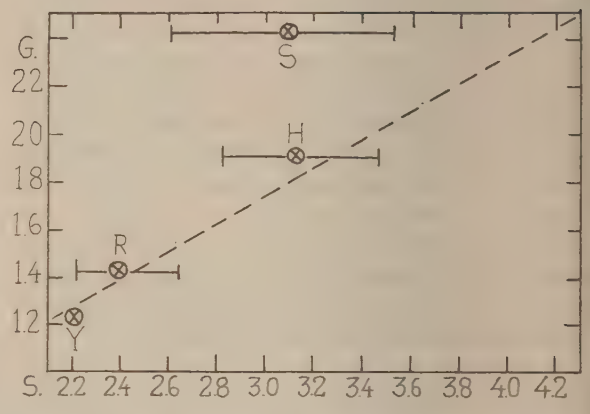

Fig. 34. The relation of selection factors (S) to girth factor (G). Range of selection factors indicated by line, average factor by encircled "X". S = silver hake, H = haddock, R = redfish, Y = yellowtail.

for hake appears to be very much lower than its girth factor would indicate.

A summary of selection factors for the European species of *Merluccius* (Gulland 1956) indicates an average of 4.1, which is in good agreement with the derived line of Figure 1 and much higher than our data indicate.

The poor fit of the silver hake data to the line indicates that these fish were not fully utilizing their escape potential during our experiments. The poor escapement could, perhaps, be due to lack of an escape response to whatever stimulus is provided by the imminence of the trawl meshes.

Derivation of Potential Escape Index

The possibility of escape is limited to fish whose maximum girth is not larger than the circumference of the mesh. With girth less than mesh circumference, the more nearly the cross sectional shape of a fish approximates the shape taken by the mesh of the net under tow, the better should be its chances of escaping. The situation is illustrated in Figure 35. For a mesh having the shape indicated, a fish of oval cross section, such as a silver hake, has the optimum shape for escapement. In theory, a more elongated mesh

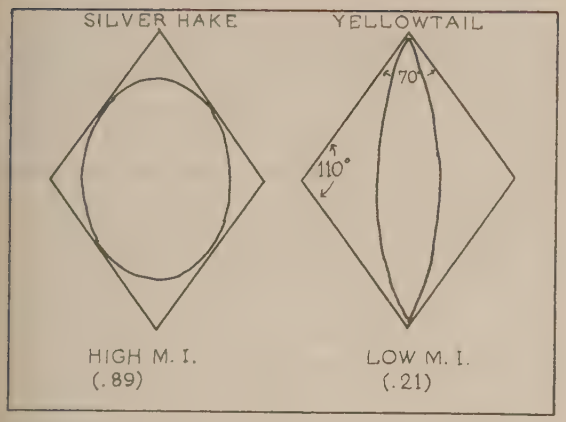

Fig. 35. Diagrammatic representation of the relation of fish shape to mesh shape.

would favor escapement of a deep fish such as yellowtail flounder, but the orientation of long axis of fish to long axis of mesh will be more important, and the angle of approach becomes critical.

The relation between fish dimension and mesh dimension which we have termed the *mesh index* (M.I.) may be defined as follows:

$$1.0 > \text{M.I.} = \text{A/B or B/A}$$

where A = fish breadth/fish depth
B = mesh length/mesh width.

The mesh index may be used to adjust the girth factor for the relation of fish shape to mesh shape. The adjusted girth factor provides a measure of the maximum possible escapement size for a particular species and mesh shape. This we have termed the *potential escape index* (P.E.I.) which is defined as the square root of the product of girth factor times mesh index:

$$\text{P.E.I.} = \sqrt{\text{G.F. x M.I.}}$$

In order to relate the actual escapement under various conditions to potential escapement, we have developed the *escape response index* (E.R.I.) which is the selection factor (S.F.) divided by potential escape index:

$$\text{E.R.I.} = \text{S.F./P.E.I.}$$

The escape response index measures how well a fish utilizes its physical potential for escape based upon the relation of its cross-sectional shape to the shape of the mesh.

Application of Escape Response Index

As an example of the use of the escape response index in helping to shed light on complex selection problems, its application to the curious problem of the low selection factor for our silver hake is illustrated below.

The relation between breadth and depth (A) of silver hake is 0.79. For a mesh having angles of 70° and 110° (*see* Figure 35), the relation between its length and width (B) is 0.7. The mesh index is, then, 0.79/0.7 or 0.89. Now the girth factor is 2.4 and the selection factor is 3.1. The escape response index becomes:

$$\text{E.R.I.} = 3.1\ \sqrt{2.4 \text{ x } .89}$$
$$= 2.1$$

This is much lower than the E.R.I. for any other species shown in Figure 34:

Yellowtail flounder	= 4.4
Haddock	= 3.4
Redfish	= 2.6

We are thus led to believe that the low selection factors for silver hake have resulted from a low level of escape response under average conditions.

Verification of this result occurred when a blue shark (*Prionace glauca*) was caught in the codend during one tow of the silver hake escapement experiments. This stimulus resulted in an increased escape response caused, apparently, by fright. The incident occurred during the second of four successive tows with the same codend made on the same day in the same locality.

The detailed data for the three normal tows and for the shark tow are given in Table F-31. The three normal tows averaged 411 fish in the cover and 526 in the codend. The shark tow yielded 699 fish in the cover and only 222 in the codend.

The selection factor was 3.4 for the normal tows and 4.1 for the shark tow; the 50% point advanced from 33.0* to 39.9* cm. The selection curves in Figure 36 show the pronounced effect upon escapement produced by the stimulus (shark).

The escape response index calculated on the basis of this tow is:

$$\text{E.R.I.} = 4.1\ \sqrt{2.4 \text{ x } .89} = 2.8$$

and is thus higher than the E.R.I. for redfish.

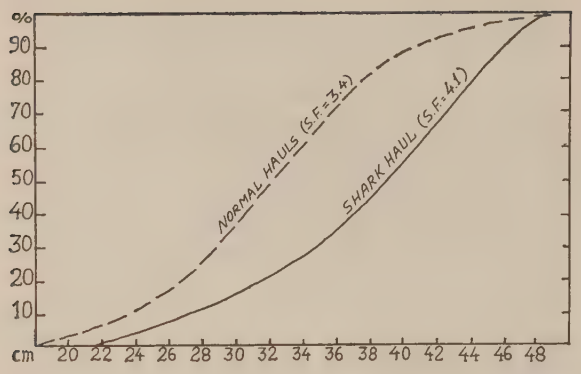

Fig. 36. Selection curves for silver hake for normal tows and shark tow. Ordinate - % retained; abscisse - length of fish, cm.

The possibility exists that the mesh index was altered by distortion of the meshes owing to the struggles of the shark in the net, thus providing more favorable escape conditions. Another possibility is that the shark in his struggling actually forced greater quantities of silver hake through the meshes than would normally be the case. These two possibilities are remote, however, and we favor the conclusion that a greater escape response motivation, owing to the stimulus afforded by the shark, was the causative factor.

It will be noted that the selection factor of 4.1 for the shark tow agrees with that which would be predicted for silver hake by the line in Figure 1. It also agrees with results for the European species. Why the escape response should have been so low in the normal course of our experiments is a question which cannot be answered at present. It may be inherent to the psychological make-up of the species.

G. ESCAPEMENT OF HADDOCK THROUGH CODEND MESHES

Abstract

Replicate tow and covered codend methods were used to determine the selectivity of codends of cotton, manila, and synthetic twines ranging in mesh size from 73 to 167 mm. Selection factors representing 40 experiments are presented. Codends of 45/4 to 75/4 double manila twine yielded selection factors of 3.0 to 3.5 Codends of single nylon twine yielded selection factors of 3.1 to 3.8. One Dacron codend tested yielded a selection factor of 3.1.

Variations in selection factor were shown to be associated with number of fish caught per tow, increasing catches yielding decreasing selection factors, and, for synthetics, with the size of meshes in the after part of the codend relative to the average size for the whole codend.

Introduction

The results of many experiments on factors affecting escapement of haddock through codends have been given in the preceding chapters. The remaining data and a summary of all escapement results for the species are presented herein.

Methods

We have determined escapement from codend meshes with the covered codend method and the replicate tow method. A brief description of these methods is given below.

The covered codend method consists of applying covering netting of small size mesh around the codend, either covering it entirely or covering only the parts from which fish are likely to escape. This method is explained in detail in the introductory chapter.

The covers used varied somewhat in dimensions, material and mesh size but usually were of 38 mm. ($1\frac{1}{2}$ inch) cotton mesh rigged to allow about 20% slack transversely (relative to the codend) to allow the netting to stand well away from the codend meshes. The lower side of the codend was covered by chafing gear of some sort, usually hides, for most of its length. The bag (*i.e.* codend) attached to the end of the cover was 8 to 12 feet long and joined at its upper side to the cover and at its lower side to the upper side of the codend, a few meshes ahead of the lachets.

This method of attachment provided for maximum ease of handling in that the codend could be emptied independently of the cover bag.

We have shown in a previous chapter that the covered codend method, if properly controlled, gives valid results for haddock.

The replicate tow method requires the towing of two nets which are identical except that one net is rigged with the codend to be tested and the other with a smaller mesh (control) codend. The difference in the catches of the two provides an estimate of the escapement from the larger mesh codend.

The validity of this method has been questioned chiefly because of the difficulty in insuring that equal numbers of fish of each size have actually entered the two codends to be compared. The data from replicate tow experiments are often adjusted by some method to remove the effect of such inequalities as are shown to arise.

The adjustment is usually made by choosing an arbitrary 100% retention size and multiplying the numbers at each length in the catch of either codend by a factor which will equalize the numbers above the 100% size. In using such an adjustment one must assume that the proportions of fish of each size entering the two codends are equal. The adjustments and assumptions employed in these experiments admit rather serious sources of error to the results. We have attached (as App. B) the results of an experiment carried out by the *Albatross III* in 1949 as an example of the results obtained with alternate tows. This experiment yielded a selection factor of 3.8 to 4.0 which is much higher than any obtained from other methods. The results were not accepted because of their anomalous nature, and we employed other methods in subsequent tests of codend selection.

Most of our selectivity experiments were done by the covered codend method described above. We did, however, engage in a modification of the replicate tow method which eliminates many sources of variation. This modification, which requires the use of two vessels, we term "paired tows." The two vessels employed in experiments were the *Albatross III* and the *Delaware*[1] which are of about equal fishing ability.

Great care was taken to assure that the No. 41 nets used by each were rigged in identical manner. We used on each net the same size and weight of "doors," number of floats, and length of headline and footline. Netting components and other attachments were of the same size and specifications. The only difference was in the mesh size of the codends. One vessel used the codend to be tested; the other used a similar codend but of a smaller mesh size. The catches of each size of fish in the two codends were compared in the manner usual to replicate tow experiments.

We attempted to have the boats fish simultaneously, and they usually succeeded in setting and hauling back within a few minutes of each other. The two nets were towed for equal periods of time and as closely together as safety would permit. The vessels usually set their nets well apart from each other, then converged while towing, separating again about 5 minutes before haul-back time. In spite of the precautions taken, many of the pairs were unacceptable for our analysis and the results from them not used.

Results from Paired Tows

All of our paired tow results have come from operation Pairtows I, carried out on Georges Bank by the *Albatross III* and *Delaware*, October and November 1955. The experiments to be discussed herein were carried out in the following five phases:

Phase I – Standardization
Phase II – Selectivity of 119 mm manila
Phase III – Selectivity of 144 mm cotton
Phase IV – Selectivity of 106 mm cotton (58 mm control codend)
Phase V – Selectivity of 111 mm cotton (86 mm control codend)

Phase I - Standardization. We intended, through reduction of variables in gear construction and methods of operation, to eliminate sources of bias and the necessity for adjusting the data. To ascertain whether we had eliminated bias caused by different catching rates of the two

[1]) Characteristics of these vessels and gear are described elsewhere (see page 27).

nets for various sizes of haddock, we conducted a series of "standardization" tows, in which the identical nets had codends of nearly equal mesh size (*Albatross III*, 59 mm; *Delaware*, 56 mm) The difference of 3 mm has little bearing on the results because insignificant numbers were taken within the selection range of these mesh sizes. The results from the 12 paired tows conducted in this phase are given in Table F-32. The two different areas fished were typified by size compositions having modes of 51 cm in one instance and 40-41 cm in the other. We thus had the advantage of testing the nets with two entirely different length compositions and density levels.

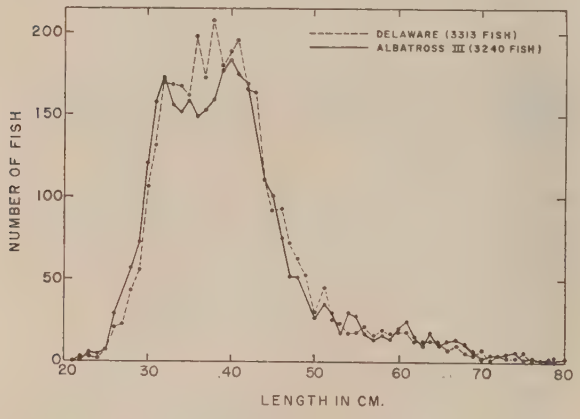

Fig. 37. Pairtows I, Phase I. Catches by *Delaware* and *Albatross III* with manila codends of 56 and 59 mm mesh.

The total numbers of each size of haddock taken by the two nets are plotted in Figure 37. We see from the graph that the two size distributions are quite similar. A discrepancy occurs at 36, 37 and 38 cm where the *Albatross III* catches were only 80% of the *Delaware's*. The *Delaware* caught only 85% as many fish of 26 to 32 cm as the *Albatross III*, however. Other lesser differences are evident. The catch of the *Delaware* of haddock of all lengths exceeded that of the *Albatross III* by about 4%. As the differences are not consistent, we may assume that they are owing to random causes and in any event not indicative of an overall difference in efficiency.

Another series of paired tows with identical nets which was carried out on operation Pairtows II for standardization purposes is reported in a previous paper in this series. The gear was essentially the same as that used in the above experiment. These results also showed that the nets of the two vessels caught equal numbers of fish of various sizes (*see* p. 38).

Phase II - Manila. This experiment was conducted to determine the selectivity of a 45/4 double manila codend of 119 mm mesh size. It directly followed Phase I, and we simply replaced the *Delaware's* 56 mm codend with the larger mesh codend and continued making pairs of tows against the *Albatross III's* 59 mm codend. A total of 11 successful tow pairs was completed.

No difference in relative speeds of the two vessels could be detected when the larger mesh was used on the *Delaware*. The vessels operated so close to each other that any measurable difference in speed would have been easily detected. This observation is of importance because many investigators have thought that the increase in efficiency caused by increases in codend mesh size was owing to an increase in speed of towing.

The data are given in Table F-33. An estimate of the selectivity of the 119 mm codend is obtained by calculating the percentage that the *Delaware* catch is of the *Albatross III* catch for each size interval. These percentages are shown in the table and plotted as a selection curve in Figure 38. The 50% point of 39.6* cm estimated from the selection curve, yields a selection factor of 3.3.

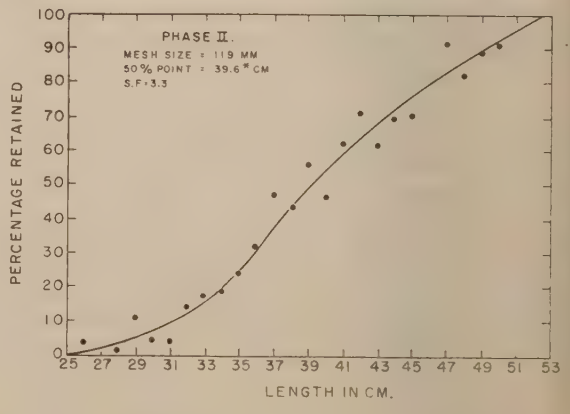

Fig. 38. Pairtows I, Phase II. Retention of sizes of haddock by a 119 mm mesh manila codend.

Phase III - Cotton. A series of 4 pairs of tows was completed with a single 120 thread cotton codend of 144 mm. mesh (*Albatross III*) and one of 84 thread, 57 mm mesh (*Delaware*). The data are given in Table F-34 and plotted as a selection curve in Figure 39. The usefulness of the data is severely restricted by a scarcity of fish within the upper end of the selection range. A 50% point of 52.4* cm may be estimated, however, providing a selection factor of 3.6 "Retention" of 100% is not attained.

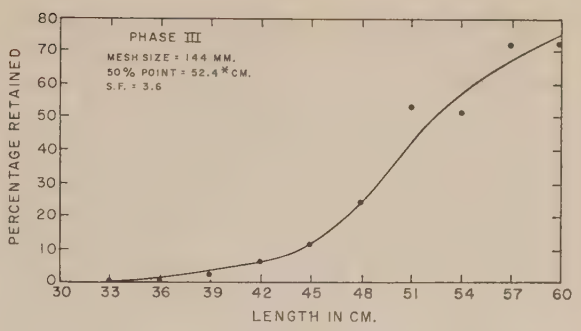

Fig. 39. Pairtows I, Phase III. Retention of sizes of haddock with a 144 mm single 120 thread cotton codend.

Phases IV and V - Cotton. A codend of single 120th cotton twine (*Delaware*) was tested against two different 84 thread control codends (*Albatross III*). The operations may be summarized as follows:

	Phase IV		Phase V	
	Mesh size (mm)	No. of pairs	Mesh size (mm)	No. of pairs
Test codend	106	8	111	12
Control codend	58		86	

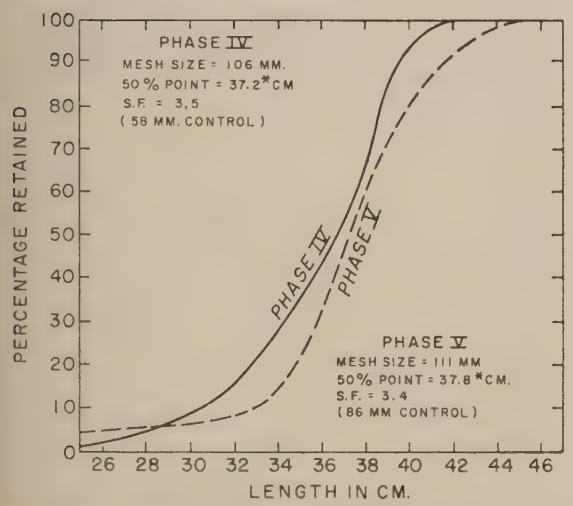

Fig. 40. Pairtows I, Phases IV and V. Retention of sizes of haddock with a single cotton codend of 106 and 111 mm. using controls of 58 and 86 mm. mesh size.

The data are given in Tables F-35 and F-36. Selection curves have been drawn for both phases in Figure 40. The curves for the two phases have somewhat different shapes owing to relatively higher retention in the middle of the selection range for the Phase V codend. The 50% points of 37.2* and 37.8* cm yield selection factors of 3.5 and 3.4 for Phase IV and V respectively. The increase in 50% point from Phase IV to Phase V is owing partially to the increase in average mesh size from 106 to 111 mm. That the escapement did not increase proportionately is shown by the decreasing selection factor. No explanation can be given for this decrease. The lower limb of the Phase V curve has undoubtedly been affected by escapement from the 86 mm. control codend, thus increasing the apparent retention.

Results with Covered Codends

We have carried out covered codend experiments for haddock with manila, cotton, and synthetic twines of various sizes. Most of the results are for double manila codends as other twines are used very infrequently in our haddock fishery. The various experiments with manila codends are considered below in the order of their occurrence.

Michigan **1 and 2.** Double manila 50/4 codends of three mesh sizes were tested during

June 1952, on two cruises of the *Michigan*. A preliminary account of these results has been published previously (Clark 1952).

In these experiments the *Michigan*, a commercial Boston trawler, modified her usual operations only to include handling of the cover catch. This catch did not exceed 1,600 pounds during the two cruises and was only rarely over 500 pounds. The four biologists aboard usually found it possible to measure the fish as fast as the six fishermen could handle them by using the "punch strip" method of measuring (*see* p. 26). In rare cases, such as the 1,600 pound catch of small fish in the cover, we were able to measure only a sample of the cover catch. Large catches in the codend (up to 5,500 pounds) prevented us from measuring any fish of the "large" category in a few instances.[2] As large haddock (about 48 cm and larger) are out of the selection range of the mesh sizes tested, the results were not affected.

In Series I we completed 11 successful tows with a codend of 92 mm mesh size (average for the 11 tows). The data for the series are given in Table F-37. Separate selection curves are plotted in Figure 41 for all 11 tows and for the last 6 tows only.

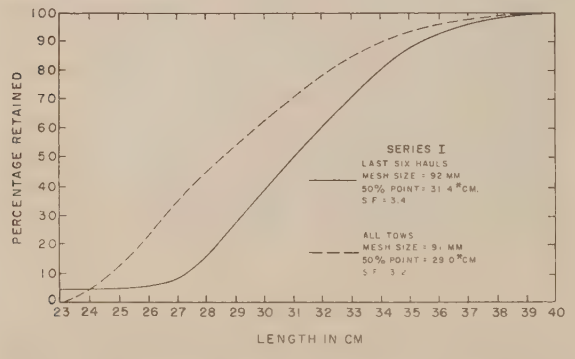

Fig. 41. *Michigan* Series I. Selection curves for a double manila 50/4 codend at 91 and 92 mm mesh size.

The curve for all tows shows the effect of poor escapement for the first five tows. The escapement in the last six tows, with mesh size only 1 mm larger than the average for all, is shown to be much greater. Conditions were the same for all tows, as far as can be determined, except that slightly different areas were fished. The selection factors of 3.2 and 3.4 obtained from these experiments agree well enough with the factor obtained from the paired tow experiment (3.3) with manila.

On this, our first such selection experiment, we did not realize the importance of changes in mesh size from tow to tow when catching large quantities of fish. Therefore, we did not measure the meshes until after tow No. 34 which was the twelfth tow with this codend. Another measurement was taken after the twentieth tow (No. 45). We have data for only 11 of the 20 tows because the *Michigan* fished continuously while we only measured fish daytimes. Our average mesh sizes for the Series I codend are based solely on the two measurements above, and our extrapolated estimates, particularly for the first several tows, may be somewhat unreliable.

In Series II we completed 5 successful tows with a codend of 98 mm. The data are given in Table F-38. The selection curve is plotted in Figure 42. A 50% of 31.4* cm was obtained, yielding a selection factor of 3.2 which is identical to that for all tows in Series I.

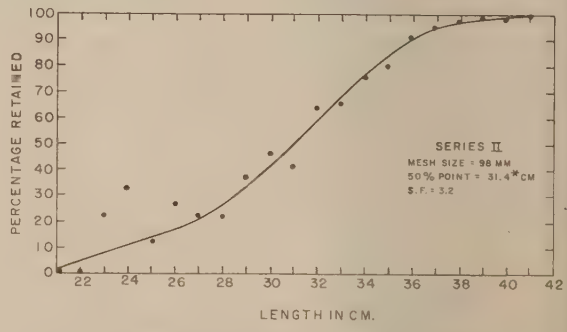

Fig. 42. *Michigan* Series II. Selection curve for a double manila 50/4 codend of 98 mm mesh.

In Series III we completed 14 successful tows with a codend which remained at 105 mm throughout the experiment (it had been used previously and was well set). The data for the series are given in Table F-39. The selection

[2]) Haddock fishermen separate their catches at sea into the following categories: *scrod* haddock, weighing less than 2.5 lb and *large* haddock weighing 2.5 lb and more.

curve is plotted in Figure 43. A 50% point of 32.3* cm was obtained, yielding a rather low selection factor of 3.1 The low selection factor appears to result from the influence of two large tows (Nos. 47 and 48) with 50% points of 30.7* cm and 30.6* cm. To determine if the size of the catch was related to escapement, we have plotted 50% points against both the weight and number of haddock taken on each tow in Figure 44. The 50% points appear to be more closely

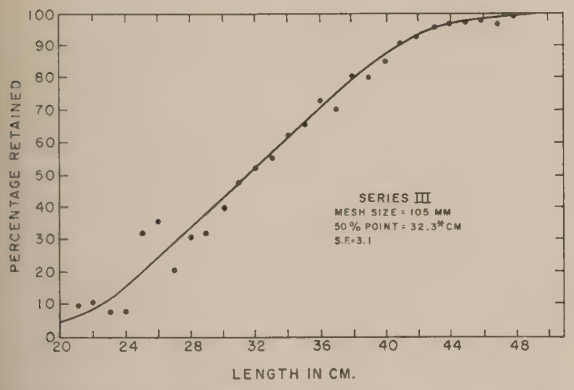

Fig. 43. *Michigan* Series III. Selection curve for a double manila 50/4 codend of 105 mm mesh.

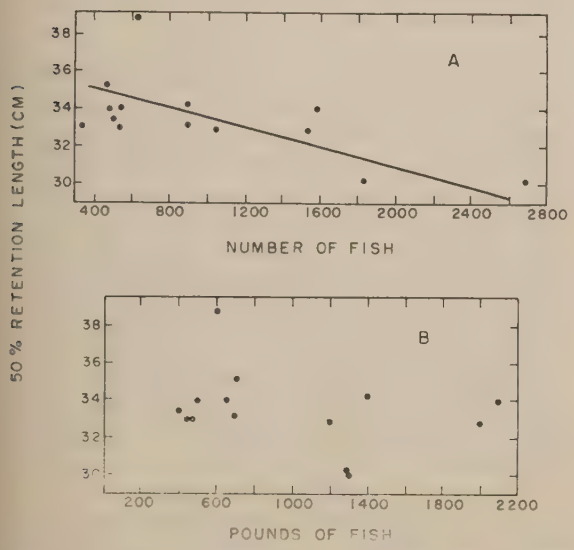

Fig. 44. *Michigan* Series III. The 50% point for each tow plotted against weight (B) and numbers (A) taken.

related to numbers than to weight. Although tows 47 and 48 exceeded all others in respect to numbers caught, they were equalled or exceeded in weights of catch by tows 2, 12, 13 and 14 which had high 50% points, ranging from 33.3* to 34.8* cm. We may then infer that the lowered escapement was perhaps owing not to greater weight but to greater numbers of fish in the codend. The reason for this is not clear since it would appear that the bulk of fish blocking the meshes would be the more important inhibiting factor.[3] Perhaps it is caused by an active competition among the fish for the larger individual meshes of the codend.

Wisconsin. Two double manila 50/4 codends were tested on a cruise of the *Wisconsin* in October 1952, using the same procedure as that described for the *Michigan* experiments.

In Series I we completed 17 successful tows for a codend with a mesh size which increased from 109 to 114 mm and averaged 112 mm. The data are given in Table F-40. A 50% point of 36.1*cm was determined from all 17 hauls, yielding a selection factor of 3.2. To study the effect of increasing mesh size upon the escapement, we divided the tows into groups on the basis of significant changes in mesh size. This division put 5 tows in Group I, 9 in Group II, and 3 in Group III. Selection curves for the three groups thus established are presented in Figure 45. We see that Group II and Group III curves

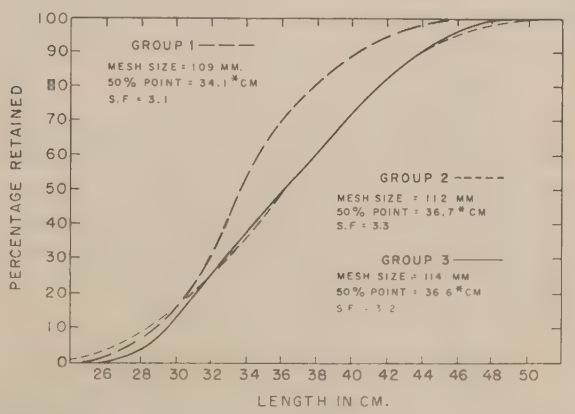

Fig. 45. *Wisconsin* Series I. Selection curves at three mesh sizes for a double manila 50/4 codend.

[3] Upon completion of Series III the codend was reversed, replacing the larger meshes at the after end with the smaller meshes normal to the forward end. This reversal, reported on p. 32 resulted in a great reduction in escapement.

are nearly identical from 31 cm on. That the selection factor for Group II is higher may be owing to error in measurement or subsequent interpolation of mesh sizes. The curve for Group I, however, shows distinctly lower escapement. This may be due to the small catches taken in the initial tows which did not allow the meshes to become well "set." We have observed that the heavy twine of such codends remains rather gnarled until a good tow or two is made. The meshes will yield to the gauge and probably indicate a relatively larger mesh than is actually the case while being towed.

The relation between numbers caught per tow and 50% point is shown in Figure 46. A negative relation, similar to that of *Michigan* Series III data, holds generally for all groups combined. Within individual groups the relationship is consistent only for Group II, however, catch size appearing to have no significant effect for the other two groups.

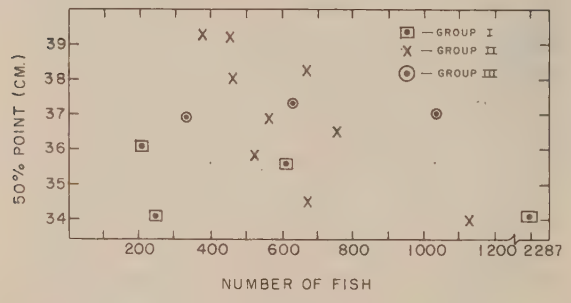

Fig. 46. *Wisconsin* Series I. Number of fish per haul and 50% points for 112 mm codend of 50/4 manila, double.

In Series II we completed 8 successful hauls with a codend of 121 mm. Catches were generally low, averaging less than 400 fish per haul. The data are given in Table F-41, and the selection curve is shown in Figure 47. A 50% point of 39.9* cm was obtained, yielding a selection factor of 3.3.

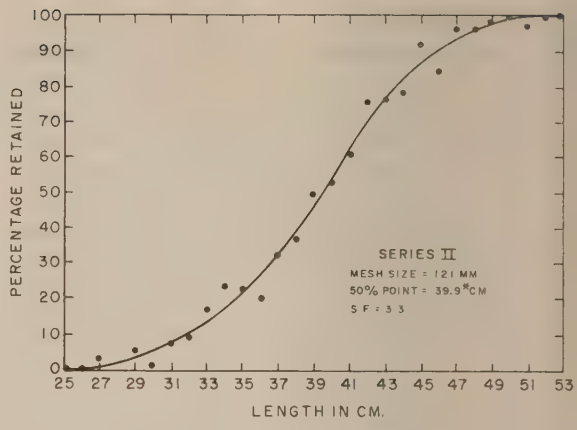

Fig. 47. *Wisconsin* Series II. Selection curve for a double manila 50/4 codend of 121 mm mesh.

High escapement on certain tows in this series appeared to be associated with the presence of mackerel in the cover. We cannot do more than note this occurrence because our records of incidental species are limited to general notes rather than quantitative estimates. We did, for instance, record that 1,500 pounds of mackerel were taken in the cover on tow 28 which was characterized by high escapement and yielded a selection factor of about 3.5.

Albatross III - **No. 49.** Experiments with double manila codends of three mesh sizes were conducted on Cruise No. 49. The primary purpose was to investigate the effect of length of tow on escapement. We also made tows, with and without hides under the codend, to investigate escapement through the lower side of the codend. These results, discussed in other papers in this series, show that the removal of hides had little effect upon catches in the cover relative to catches in the codend. Increasing the length of tow increased the escapement. The results for the three codends may be summarized as follows:

Series	Mesh Size (mm)	Type	Selection factor for tows of 20 min.	40 min.	60 min.	80 min.
I	113	50/4	3.0	3.1	3.3	3.4
II	123	45/4	—	3.0	3.2	3.3
III	73	75/4	—	3.4	3.5	3.4

The summary shows that the heavy 45/4 twine yielded the lowest escapement. The light 75/4 twine, in general, yielded the highest escapement, and the 50/4 twine gave intermediate results. (The results for 60 and 80 minute tows are the mose useful because large U.S. haddock trawlers normally make tows of 70-80 minute duration.)

Albatross III - **No. 51.** Two series of tows with double manila codends were conducted on Cruise No. 51 in June 1953.

In Series I we completed 8 successful hauls with a 45/4 codend of 107 mm mesh size. The data are given in Table F-42, and the selection curve is plotted in Figure 48. A 50% point of 31.8* cm. was obtained, yielding a selection factor of 3.0. The low escapement from this cod end is owing in part to the fact that catches were too light to set the meshes, and the heavy 45/4 twine remained gnarled throughout the series. The one-hour tows made should have given a selection factor of 3.2 on the basis of the results obtained in the *Albatross III* No. 49 experiments. The *Albatross III* codend (123 mm internal size) was ordered to be the same size new, but had been stretched out better as shown by the difference of 16 mm in mesh size.

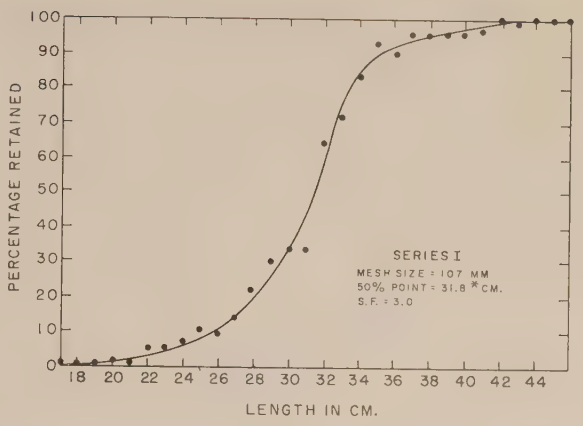

Fig. 48. *Albatross III* No. 51, Series I. Selection curve for a double manila 45/4 codend of 107 mm mesh.

In Series II we obtained additional results for the 73 mm. *Albatross III* No. 49, 75/4 codend.[4] We have plotted from these data the selection curve in Figure 49. The average mesh size of 75 mm obtaining during these tows was 2 mm

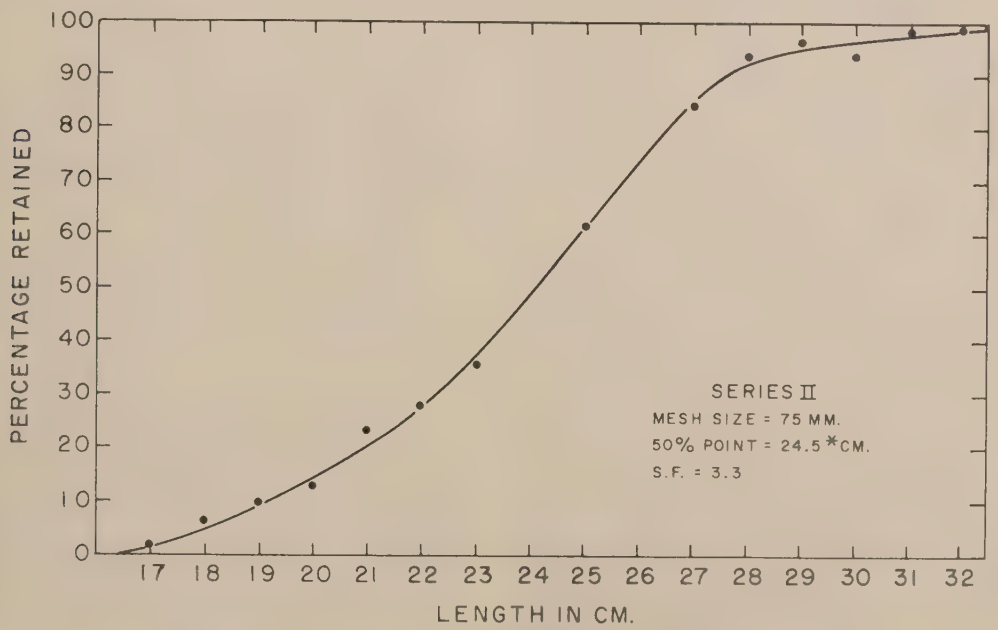

Fig. 49. *Albatross III* No. 51, Series II. Selection curve for a double manila 75/4 codend of 75 mm mesh.

4) The primary purpose of these tows was investigation of the validity of the effect of duration of tow. The results of this investigation and the data obtained are given in another paper in this series.

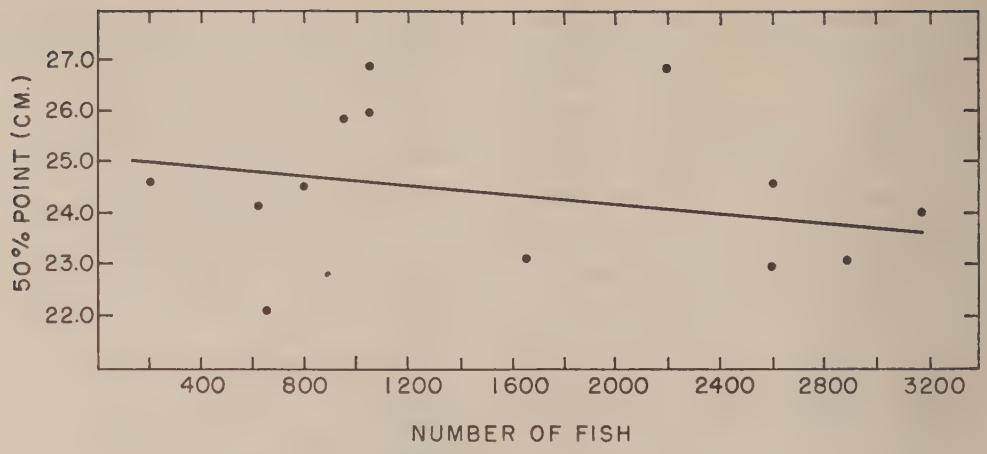

Fig. 50. *Albatross III* No. 51, Series II. Numbers caught and 50% points for a 75/4 double manila codend of 75 mm mesh.

higher than during the *Albatross III* No. 49 experiments. The 50% point of 24.5* cm yields a selection factor of 3.3 which is lower than 3.5 obtained from tows of the same length (60 min.) during the earlier experiments. Catches were three times as large, which we know now could very well have reduced the escapement. The relation between numbers caught and 50% point for each tow is shown in Figure 50. The relationship is weak, but an average of tows of less than 1,100 fish yields a selection factor of 3.4 while the large tows yield a selection factor of 3.3

Albatross III - **No. 52.** A series of 12 tows is available from a cover validity study conducted on Cruise No. 52 in July 1953. (The validity results are discussed in another paper in this series). The codend employed was of 45/4 double manila and averaged 113 mm for all tows. Although catches were only moderate, the mesh size increased from about 110 to 115 mm over the course of the experiments. (The data are considered in the paper mentioned above.) The selection curve is plotted in Figure 51. A 50% point of 36.8* cm was obtained, yielding a selection factor of 3.3 These results agree well with *Albatross III* No. 49 results for the same tow length (60 min.); the selection factors differ by only 0.03.

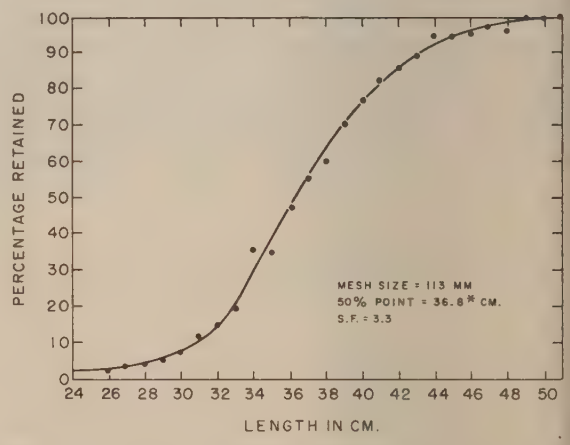

Fig. 51. *Albatross III* No. 52. Selection curve for a double manila 45/4 codend of 113 mm mesh.

Albatross III - **No. 59.** We tested three very large mesh double manila 45/4 codends on Cruise No. 59. An abundance of the large sizes required for these codends was located south of LaHave Bank (Subarea 4). Our previous studies had all been conducted on Georges Bank (Subarea 5). All tows were made within a restricted part of these grounds over a period of six days. No significant change in mesh size was observed for any codend during the course of the experiments. We thus were able to eliminate many

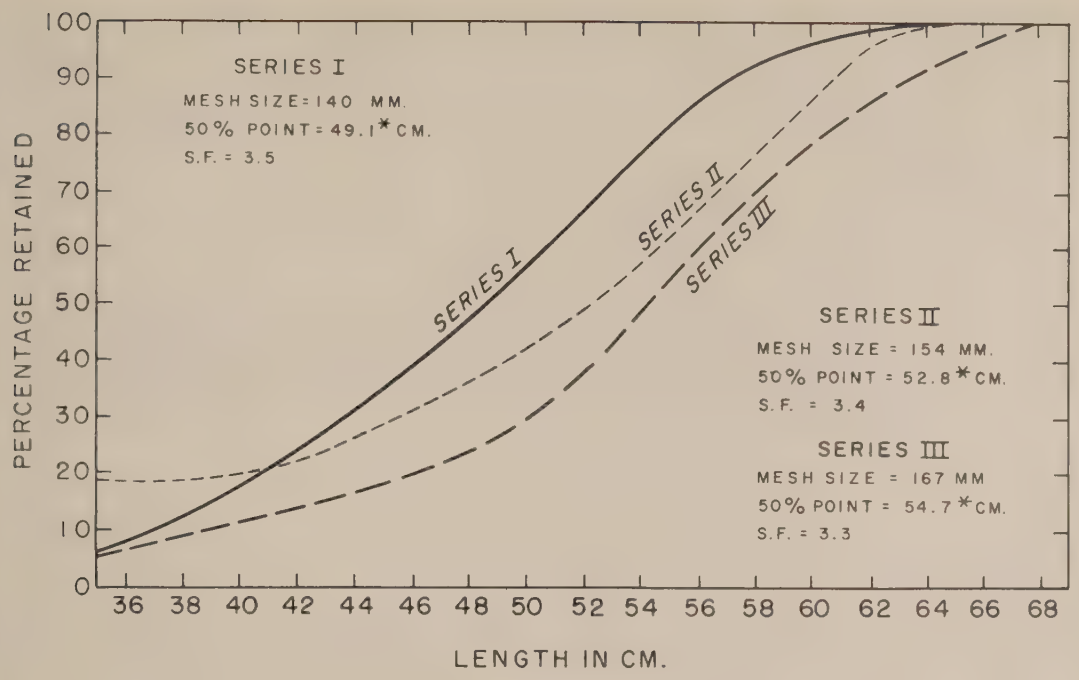

Fig. 52. *Albatross III* No. 59. Selection curves for double manila codends of 140, 154, and 167 mm mesh.

causes of variation which are troublesome in the comparison of results for various experiments. Ten successful tows were completed for each series. The data are given in Tables F-43, F-44 and F-45. Selection curves for each series are plotted in Figure 52. The results of the three series are summarized as follows:

	Series I	Series II	Series III
Selection factor	3.5	3.4	3.3
Mesh size (mm)	140	154	167
50% point (cm)	49.1*	52.8*	54.7*
Range of 50% points for individual tows (cm)	45-53	48-55	53-58
Average number of fish per tow	550	454	345
Range of numbers of fish per tow	342-785	326-630	276-500
Average tow duration (min.)	56	54	60

The selection factors are shown to decrease with increased mesh size. The average number of fish per tow also decreases, suggesting a positive correlation between number caught and escapement. This matter is elucidated in Figure 53 where we have plotted 50% points and numbers per tow for each series. The figure shows that the reverse is actually true; *i.e.*, a negative relation between catch size and 50% point is indicated. We must, therefore, assume that the differences in selection factor among the three series were owing to some cause other than numbers caught

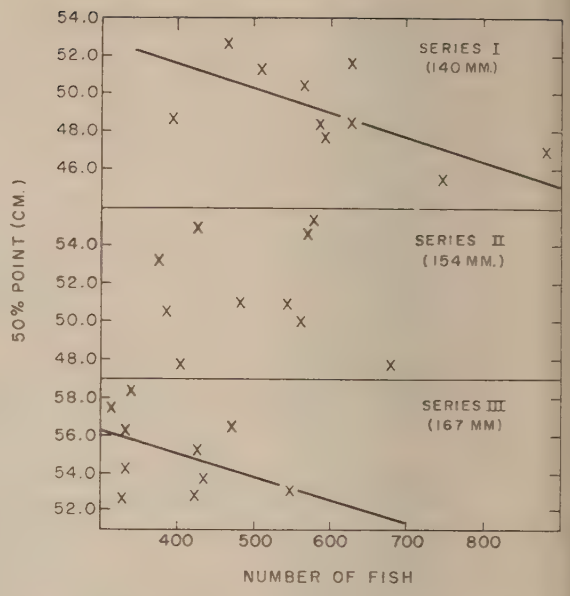

Fig. 53. *Albatross III* No. 59. Numbers of fish per tow and 50% points for three double manila 45/4 codends.

Cotton - Pairtows I and *Priscilla V.* Three series of tows with single cotton codends. of different mesh size and twine weights were carried out during the Pairtows I experiments. Some of the results are from studies on the validity of the covered codend method (*see* p. 41). Some haddock were also taken by a covered cotton codend during the *Priscilla V* silver hake experiments. These experiments have produced only limited results which may be summarized briefly as follows:

Experiment	Twine weight	Mesh size (mm)	50% point	Selection factor	No. of tows	No. of fish in cov.	No. of fish in c.e.
Pairtows I	120 th	138	49.6*	3.6	5	2289	305
Pairtows I	120 th	114	42.4*	3.7	8	355	501
Pairtows I	84 th	86	25.8*	3.0	6	85	2202
Priscilla V	72 th	73	20.8*	2.8	6	2157	192

Selection factors for the 138 and 114 mm codends agree well with the 3.4 to 3.6 for cotton from our paired tow results and the 3.5 and 3.6 for cotton reported by McCracken (p. 131) and by Margetts (p. 157). Selection factors for the two smaller codends of 3.0 and 2.8 appear to be underestimated. The low selection factor of 2.8 obtained from the *Priscilla V* experiments may be explained by slower towing speed and the different trawl used. Silver hake escapement also was very much lower than expected in these experiments (results appear in another paper in this series - *see* p. 81).

The occurrence of the low selection factor of 3.0 for the 86 mm codend cannot be easily rationalized. The experiment was conducted in exactly the same manner as the experiments with the two larger mesh sizes.

Nylon and Dacron - *Albatross III* **No. 74.** Covered codend experiments with various sizes of nylon and Dacron codends were conducted on Cruise No. 74 in May 1956.

The nylon used was a loosely braided twine developed for making cargo nets. It runs approximately 43 yards per pound and has a tensile strength of 1,000 pounds. While it has not won popularity with the larger trawlers, this twine has come into use in the "dragger" fleet (30-150 gross tons) in recent years.

The Dacron twine, manufactured especially for codends, was tightly braided and yet flexible,

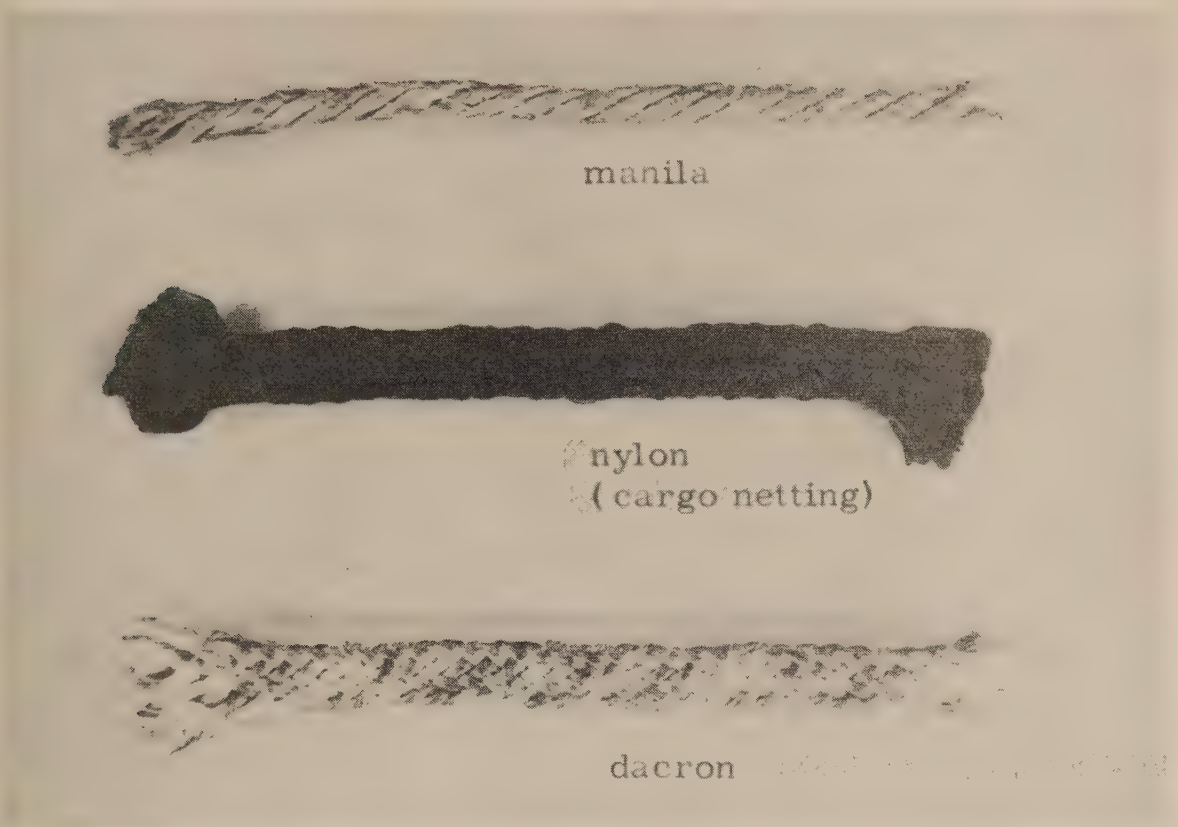

Fig. 54. Nylon (cargo netting type), Dacron, and 50/4 manila twine used in the selection experiments, Actual size.

although not as much so as the nylon. The two types of twine are illustrated in Figure 54 in comparison with manila.

None of the codends used increased in mesh size significantly during the experiments. The Dacron and nylon experiments may be summarized as follows:

Series	Material	Mesh size: Whole codend (mm)	Mesh size: Last 10 meshes (mm)	No. of tows	No. of fish in: cov.	No. of fish in: c.e.	50% point (cm)	Selection factor	Refer to Table No.
I	Dacron	127	124	15	2106	4619	39.8*	3.1	F-46
II	Nylon	105	113	11	2831	2378	40.2*	3.8	F-47
III	Nylon	134	134	14	2113	3075	46.1*	3.4	F-48
IVa	Nylon	122	119	10	931	2460	37.4*	3.1	F-49
IVb	Nylon	124	133	12	3259	2143	44.4*	3.5	F-50

From the selection curve for dacron plotted in Figure 55 we obtained a low selection factor of 3.1. The results, based on large numbers of fish and many tows, must be considered valid for this codend.

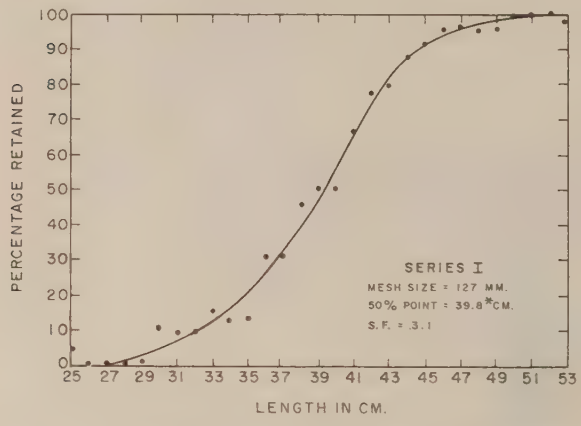

Fig. 55. *Albatross III* No. 74, Series I. Selection curve for a single dacron codend of 127 mm mesh.

From the selection curves for the Series II and III nylon codends of 105 and 134 mm plotted in Figures 56 and 57, we obtained selection factors of 3.4 and 3.8, indicating high escapement. The difference of 0.4 between the two selection factors must be assumed to be substantive because of the extensive series of tows involved and the large numbers of fish caught (5,209 and 5,188).

Series IVa and IVb results are for one nylon codend. The codend had been used previously, and the meshes were enlarged at the after end. For our experiments the codend was initially installed with these larger meshes forward. This arrangement resulted in very poor escapement, yielding a selection factor of 3.1. We were troubled by the low selection factor and reversed the codend, putting the larger meshes aft in an attempt to improve the escapement. The selection factor increased to 3.5 after the reversal. The selection curves for both series are shown in Figure 58. The increase in escapement effected through the reversal is consistent with studies reported in a previous paper in this series in which we demonstrated that most escapement takes place in the after end of the codend (*see* p. 36).

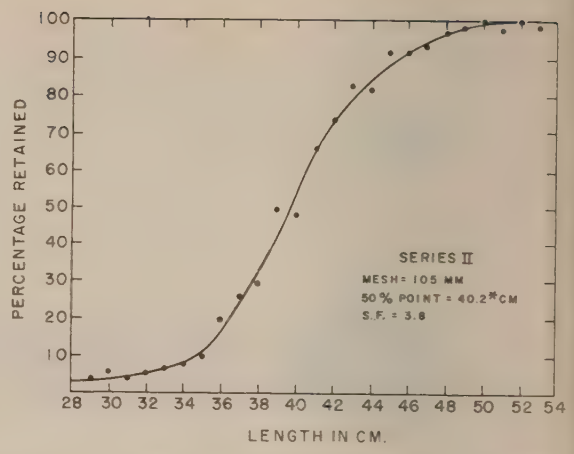

Fig. 56. *Albatross III* No. 74, Series II. Selection curve for a single nylon codend of 105 mm mesh.

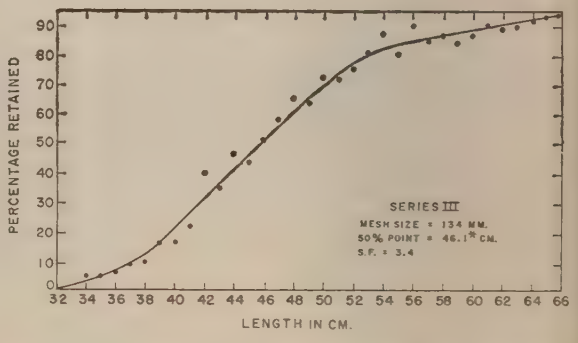

Fig. 57. *Albatross III* No. 74, Series III. Selection curve for a single nylon codend of 134 mm mesh.

Series I results with dacron provided a selection factor of 3.1 which is the same as for the Series IVa results. We also see (from summary table above) that the dacron codend had relatively small meshes at the after end. The average mesh size for the after 10 rows of meshes was 3 mm less than that for the whole codend in both cases. Both the over-all and the after section averages were the same (134 mm) for the Series III codend which yielded moderately good escapement. High escapement obtained for Series II and IVb where the average sizes for the after meshes were 8 and 9 mm larger than those of the whole codend.

For Series I, III, IVa, and IVb a negative relation between 50% point and numbers of haddock per tow may be seen. Numbers per

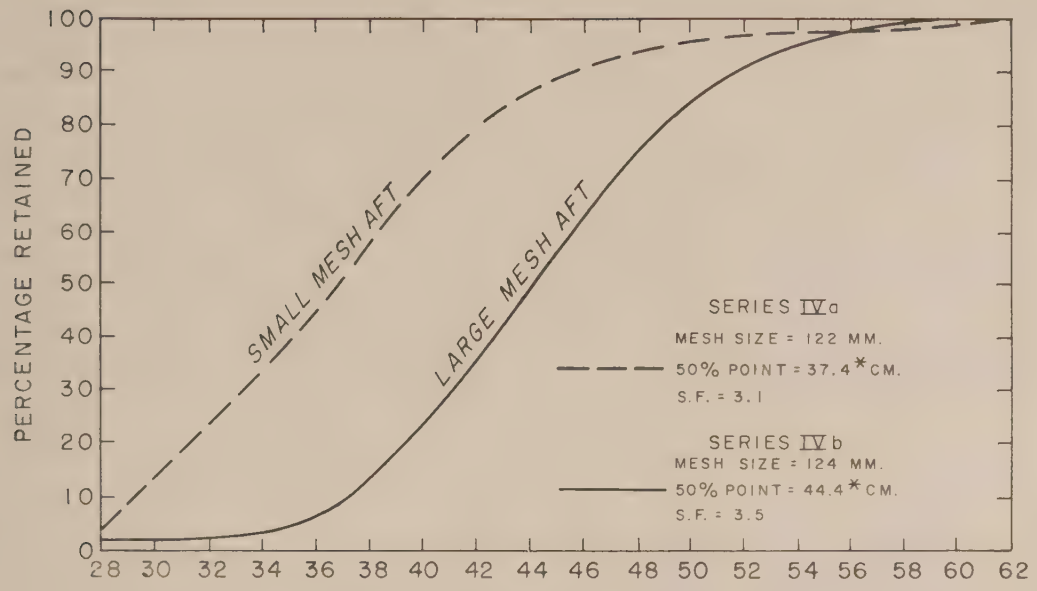

Fig. 58. *Albatross III* No. 74, Series IVa and IVb. Selection curve for a single nylon codend before and after reversal.

tow and 50% points are plotted for each series in Figures 59 to 63. Similar reductions in escapement associated with increasing size of catch have been demonstrated many times previously in this paper. The relations, as always, contain much variation but appear consistent enough to confirm previous results and to assist us in understanding the large differences we find in escapement from tow to tow and experiment to experiment.

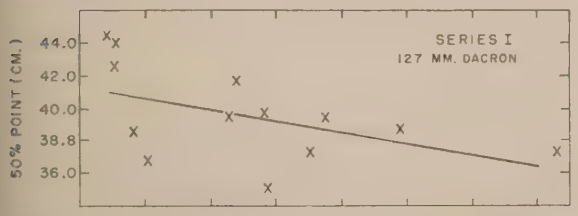

Fig. 59. *Albatross III*, No. 74, Series I. Numbers per tow and 50% points.

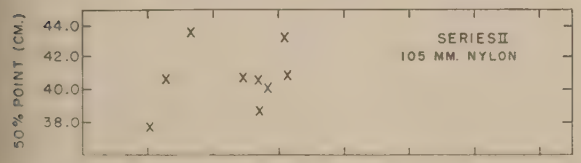

Fig. 60. *Albatross III* No. 74, Series II. Numbers per tow and 50% points.

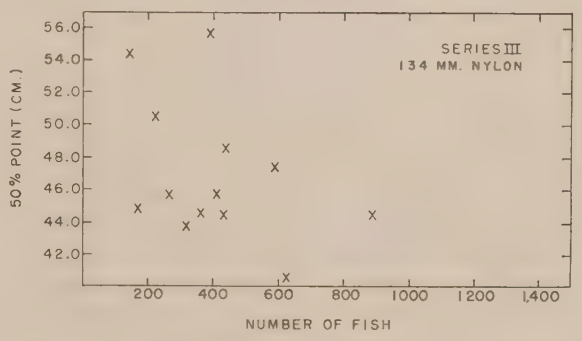

Fig. 61. *Albatross III* No. 74, Series III. Numbers per tow and 50% points.

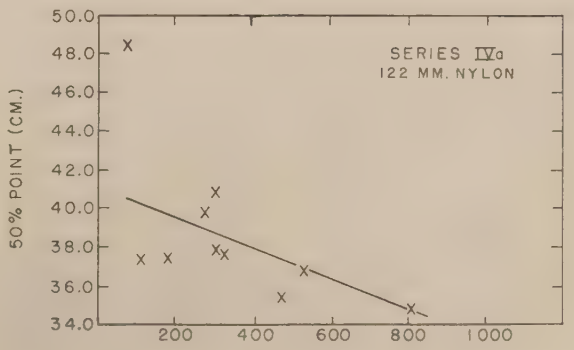

Fig. 62. *Albatross III* No. 74, Series IVa. Numbers per tow and 50% points.

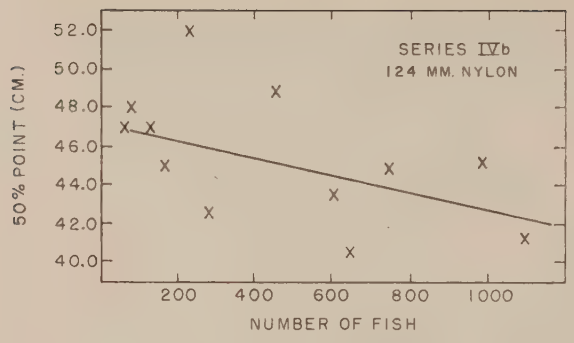

Fig. 63. *Albatross III* No. 74, Series IVb. Numbers per tow and 50% points.

Pairtows I and *Priscilla V*. Three series of tows with braided nylon (cargo netting) codends were carried out during the Pairtows I experiments. Some of the results have come from studies on the validity of the covered codend method, reported in another chapter in this series. Some haddock were also taken by a covered nylon codend on the *Priscilla V* silver hake experiments. The *Priscilla V* codend was made of a very light (400/3) twisted nylon twine.

These experiments have produced only limited results which may be summarized as follows:

Experiment	Twine spec's.	Mesh size: Whole codend (mm)	Mesh size: After quarter (mm)	No. of tows	No. of fish in: cov.	No. of fish in: c.e.	50% point (cm)	Selecton factor
Pairtows I	Braided 43 yd	135	130	3	1167	215	44.6*	3.3
Pairtows I	Braided 43 yd	107	113	7	285	854	44.3*	4.1
Pairtows I	Braided 43 yd	146	144	2	161	528	46.5*	3.2
Priscilla V	Twisted 400/3	84	85	4	169	203	(26) *	3.1

We see from the Pairtows I results that the highest selection factor (4.1) was obtained from the codend in which the after quarter of the codend had a higher average mesh size than the whole codend. The poorer selection factors were for the codends which had a smaller average size for the after quarter than for the whole codend These results thus confirm our *Albatross III* No. 74 findings in respect to the poor escapement from the codends with relatively small meshes aft.

The selection factor for the 400/3 nylon codend was low, as we might expect from the results of our other *Priscilla V* experiments. Escapement was even poorer than the relation between after quarter size and the whole codend size would suggest.

Discussion

A most interesting comparison of experimental results with selection applied in fisheries management is afforded through data from the regulated Georges Bank haddock fishery. In another paper in this series the lengths of haddock caught by trawlers fishing with the regulation mesh (average mesh size 116 mm) is compared with the lengths caught by trawlers fishing with the pre-regulation mesh (73 mm). These comparisons, extending over a three year period, yield an average selection factor of 3.3 which is exactly that predictable from our experiments for the type of fishing conducted on Georges Bank. This is perhaps the most substantial confirmation of our experimental results. (*see* p. 88).

It was not the purpose of this study to interrelate all the experiments and exhaustively analyze all factors affecting codend mesh selection but rather to present the large quantity of data available in summary form with the requisite descriptive material. The effect of certain factors, such as numbers caught and relative mesh size at after end of codend, were introduced only where necessary to explain the variation encountered among results of the many experiments. It was thus possible to prepare our data for presentation to experienced workers in the mesh selection field in the most concentrated form. A

more exhaustive treatment of the subject is planned at a later date which will benefit from the results of the deliberations of the Lisbon conference.

Summary

Replicate tow and covered codend methods were used to determine the selectivity of codends of cotton, manila, and synthetic twines ranging in mesh size from 73 to 167 mm. Selection factors from 40 experiments are presented. Codends of 45/4 to 75/4 double manila twine yielded selection factors of 3.0 to 3.5. The variations in selection factor were shown to be associated with the number of fish caught per tow, increasing catches yielding decreasing selection factors.

Codends of single nylon twine yielded selection factors of 3.1 to 3.8. The one dacron codend tested yielded a selection factor of 3.1. The variations in selection factor were shown to be associated with numbers caught (as above) and with the size of meshes in the after part of the codend relative to the average size for the whole codend.

A summary of all experimental results for haddock is given Table 5.

TABLE 5. Summary of Haddock Escapement Experiments.

Twine type	Experimental method	Experiment	Twine weight	Mesh size mm	50% point cm	Selection factor
Double manila	Paired tows	Pairtows I	45/4	119	39.6	3.3
,, ,,	Cover	*Michigan*	50/4	91	29.0	3.2
,, ,,	,,	,,	50/4	98	31.4	3.2
,, ,,	,,	,,	50/4	105	32.3	3.1
,, ,,	,,	*Wisconsin*	50/4	109	34.1	3.1
,, ,,	,,	,,		112	36.7	3.3
,, ,,	,,	,,		114	36.6	3.2
,, ,,	,,	,,		121	39.9	3.3
,, ,,	,, 20 min. tows	*Alb.* No. 49	50/4	113	33.8	3.0
,, ,,	,, 40 ,, ,,	,, ,, ,,			35.2	3.3
,, ,,	,, 60 ,, ,,	,, ,, ,,			37.3	3.3
,, ,,	,, 80 ,, ,,	,, ,, ,,			38.6	3.4
,, ,,	,, 40 ,, ,,	,, ,, ,,	45/4	123	36.8	3.0
,, ,,	,, 60 ,, ,,	,, ,, ,,			39.7	3.2
,, ,,	,, 80 ,, ,,	,, ,, ,,			41.2	3.3
,, ,,	,, 40 ,, ,,	,, ,, ,,	75/4	73	24.8	3.4
,, ,,	,, 60 ,, ,,	,, ,, ,,			25.2	3.5
,, ,,	,, 80 ,, ,,	,, ,, ,,			24.8	3.4
,, ,,	,,	*Alb.* No. 51	45/4	107	31.8	3.0
,, ,,	,,	,, ,, ,,	75/4	75	24.5	3.3
,, ,,	,,	*Alb.* No. 52	45/4	113	36.8	3.3
,, ,,	,,	*Alb.* No. 59	45/4	140	49.1	3.5
,, ,,	,,	,, ,, ,,	45/4	154	52.8	3.4
,, ,,	,,	,, ,, ,,	45/4	167	54.7	3.3
Single cotton	Paired tows	Pairtows I	120th	144	52.4	3.6
,, ,,	,, ,,	,,	120th	106	37.2	3.5
,, ,,	,, ,,	,,	120th	111	37.8	3.4
,, ,,	Cover	,,	120th	138	49.6	3.6
,, ,,	,,	,,	120th	114	42.4	3.7
,, ,,	,,	,,	84th	86	25.8	3.0
,, ,,	,,	*Priscilla V*	72th	73	20.8	2.8
Single dacron Br.	Cover	*Alb.* No. 74		127	39.8	2.1

TABLE 5. Summary of Haddock Escapement Experiments (cont.)

Twine type	Experimental method	Experiment	Twine weight	Mesh size	50% point cm	Selection factor
Single nylon (Br.)	Cover	*Alb.* No. 74	*1000	105	40.2	3.8
,, ,, ,,	,,	,, ,, ,,	,,	134	46.1	3.4
,, ,, ,,	,,	,, ,, ,,	,,	122	37.4	3.1
,, ,, ,,	,,	,, ,, ,,	,,	124	44.4	3.5
,, ,, ,,	,,	Pairtows I	,,	146	46.5	3.2
,, ,, ,,	,,	,,	,,	135	44.6	3.3
,, ,, ,,	,,	,,	,,	107	44.3	4.1
Single nylon (twist)	,,	*Priscilla V*	400/3	84	26	3.1

Appendix

Albatross III Cruise 24 Alternate Tow Experiment

An alternate tow experiment was carried out on Georges Bank in 1949 to determine the selectivity of a codend of 75/4 (double) manila twine. The nets used were the standard 1-1/2 "Iceland" type fitted with codends of 127 and 95 mm.[1]

The results from this experiment have not been published heretofore because we were uncertain of their validity. The very fact that these results do not agree with covered net experiments, however, makes them appropriate to the study of methodology of gear selection experiments.

Haddock was the only species caught in sufficient quantity to provide meaningful results in this experiment. A series of 18 pairs of tows was completed.

The results from the original unpublished report (by Louis D. Stringer and the present author) are summarized in Table 6. The actual catch made by the 95 mm codend is shown in Column A. Because the 95 mm codend was itself selecting sizes of fish, an adjustment was employed to estimate the numbers of each size which entered it. This adjustment was based upon the percentages of each size retained in a 95 mm codend (Column B) determined by replicate tow experiments as reported by Herrington (1935)[2] The calculated total number of fish entering the 95 mm codend is shown in Column C. The actual catch made by the 127 mm codend is shown in Column D. The percentages that the 127 mm codend catch (Column D) were of the 95 mm codend adjusted catch (Column C) are shown in Column E.

These figures represent our best estimate of the selectivity of the 127 mm codend. The percentages for Column E are plotted in Figure 64, and smoothed percentages read from the graph are shown in Column F of the table.

The 50% point of 48.5* cm estimated in Figure 28 yields a selection factor of 4.8 which is much higher than those determined from covered codend experiments. If the catches of the two codends had been directly compared (*i.e.*, without adjusting for escape through the 95 mm codend), the 50% point would have been decreased only a few mm. The 25% point, however would have been decreased by about 2 cm and the 10% point by about the same amount.

1) Converted to standard measurement (pressure gauge, internal) from original measurements.

2) Herrington, W. C., 1935. Modifications in gear to curtail the destruction of undersized fish in otter trawling. *U.S. Dept. Comm. Bur. Fish.*, Inv. Report 24(1): 48 pp.

TABLE 6. Catches in 95 mm and 127 mm codends and calculated percentage retention of the 127 mm codend.

	A	B	C	D	E	F
Fish length	Numbers of fish retained by the 95 mm codend	Percentage retention of a 95 mm codend $\frac{100}{B} \times A$	Total numbers of fish which entered the 95 mm codend	Numbers of fish retained by the 127 mm codend	Unsmoothed retention of the 5-inch net (%) D/Cx100	Smoothed retention of the 5-inch net (%)
7	1	0	?	0	–	–
9	17	0	?	0	–	–
11	17	0	?	0	–	–
13	1	0	?	0	–	–
15	0	0	?	0	–	–
17	3	0	?	0	–	–
19	59	0	?	0	–	–
21	217	2	10,850	2	–	–
23	395	3	13,167	0	–	–
25	404	3	13,467	6	–	–
27	225	5	4,500	6	0.1	–
29	105	7	1,500	6	0.4	–
31	43	9	478	1	0.2	0.2
33	37	12	308	6	1.9	0.3
35	92	15	613	2	0.3	0.6
37	105	23	457	7	1.5	1.5
39	117	39	300	12	4.0	5.5
41	121	60	202	29	14.4	12.5
43	122	75	163	34	20.9	20.9
45	145	86	169	53	31.4	31.4
47	137	93	147	62	42.2	42.2
49	103	97	106	62	58.5	58.5
51	59	99	60	58	96.7	80.5
53	62	100	62	50	80.6	95.0
55	46	100	46	47	100.0+	99.5
57	22	100	22	44	100.0+	100.0
59	17	100	17	23	100.0+	100.0
61	10	100	10	20	100.0+	100.0
63	7	100	7	12	100.0+	100.0
65	12	100	12	12	100.0+	100.0
67	9	100	9	12	100.0+	100.0
69	4	100	4	4	100.0+	100.0
71	0	100	0	6	100.0+	100.0
73	3	100	3	2	67.7	100.0
75	1	100	1	2	100.0+	100.0
77	1	100	1	0	–	100.0
79	0	100	0	1	100.0+	100.0
TOTALS	2719		46,681	581		

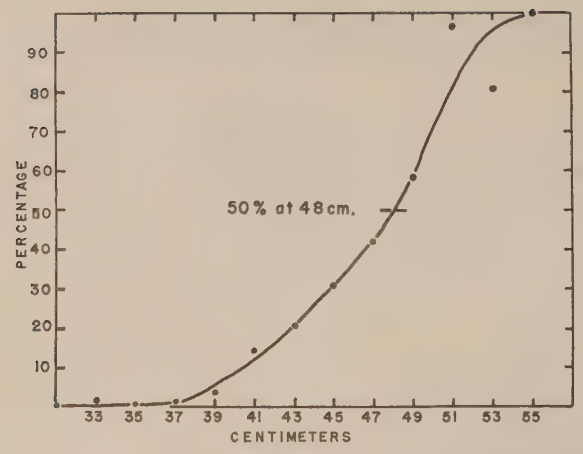

Fig. 64. The percentage of sizes of haddock retained by a double manila codend of 127 mm mesh.

Greater catches of the larger sizes of haddock were taken by the larger mesh. The 127 mm codend caught 185 fish of over 50 cm, and the 95 mm codend caught 132 of these. This phenomenon has been demonstrated by a good many other replicate tow experiments. It is customary to adjust the whole catches on the basis of the proportions of fish which are definitely past the 100% point in the two codends. The numbers of fish in the 95 mm codend would, by this method, be increased by the ratio 185/132. The results of such an adjustment would raise the 50% point to 51.5* cm, providing a selection factor of 4.1.

H. ESCAPEMENT OF SILVER HAKE THROUGH CODEND MESHES

Abstract

Covered codend experiments on the escapement of silver hake yielded selection factors of 2.6 to 3.4 for manila, 2.5 to 3.4 for cotton, and 3.2 to 3.8 for nylon. The selection factors for each type of material are shown to be linearly related to mesh size. It is suggested that the variation in selection factors results from differences in flexibility of the twines.

Introduction

A fishery for silver hake (*Merluccius bilinearis*) has been carried out for many years along the New England shores by a fleet of small draggers. Approximately 50,000 metric tons have been taken each year. Only in recent years has a fishery developed for the abundant stocks of silver hake offshore on Georges Bank. Haddock fishermen had frequently discarded great quantities of silver hake here before the Subarea 5 mesh regulation became effective. An extensive series of experiments was carred out in the autumn of 1954 to provide the mesh selection information needed to consider regulatory measures for the intensive inshore fishery and to determine the effect of diminished fishing mortality on the Georges Bank stock through use of large mesh by the haddock fleet.

Methods

The experiments were carried out aboard the *Priscilla V*, a small wooden dragger of the type that usually fishes for silver hake. Her towing speed approximates 2-1/2 knots. The characteristics of the vessel are given on p. 27.

The net employed for most of the work was a modified No. 35 cotton trawl rigged to conform as nearly as possible to average characteristics of the diverse types used in the fishery. The results for one codend (Series II) were obtained while conducting redfish selection experiments with a No. 35 manila trawl. Most tows were of one hour duration.

The experiments were restricted to the waters surrounding Cape Cod at depths of 20-40 fathoms. Some data collected incidentally while doing haddock selectivity experiments on Georges Bank with a standard No. 41 manila trawl are also reported. The trawls used in our experiments are described on p. 28. Codend escapement was measured with covers used in the manner described on p. 29.

The first three series of tows were made to study the validity of the covered codend technique. Although the cover was attached to the upper side only, most of the lower side was

usually covered by chafing gear made from worn codends. We have shown that valid selection results were obtained by covering the upper side only, basing our conclusion upon experiments with 103 mm nylon codend in which tows with upper and lower side covers were compared with tows with an upper cover only. The results of this study (*see* p. 51) describe, in addition, how an initial masking effect was eliminated through various modifications of the net and cover.

During the first two series of tows the top belly was completely covered to investigate escapement through this part of the net. In addition, a series of replicate tows was made with $2\frac{1}{2}$ and $3\frac{1}{2}$ inch mesh (knot centers, new) trawls to investigate escapement in all forward parts of the $3\frac{1}{2}$ inch net. These results are reported in another paper of this series (p. 40).

Our experiments involved ten codends of different mesh sizes made of manila, cotton, and nylon twines. All were of single construction, with the exception of one of double manila. In addition, we determined the escapement from the 35 mm mesh cotton codend bag of the cover by applying over it a secondary cover of 16 mm mesh.

Results

The quantity of length data (60,000 fish) collected during these experiments does not permit us to list the results for individual tows. Accordingly, we have simplified our presentation by giving only a summary of the length data for each codend. The original data are available in the Woods Hole files. The basic data are presented in tables F-51 to F-64, and in an Appendix of 13 figures, also filed in the Secretariat in the form of selection curves. The results for silver hake obtained incidentally in haddock selection experiments on the *Albatross III* are also given in the above mentioned Tables F-51 to F-64.

A summary account of all the *Priscilla V* results and the codend specifications are presented in Table 7. The results show that the selection factors varied greatly – from 2.5 to 3.8. Much of the variation is of a systematic nature, however, with the selection factors being related in general to the type of twine. For a given mesh size, nylon allows the highest escapement, manila the lowest, and cotton an intermediate amount. This suggests a relationship between flexibility and escapement because the most flexible material (nylon) affords the greatest escapement and the least flexible (manila) the least escapement.

TABLE 7. Summary of *Priscilla V*. Codend escapement results.

Codend Type				Mesh Size						
Series	Material	Size	Number of Tows	Makers Size in.	mm	Gauge Size, after use mm	50% point cm	Selection Factor	Number of fish in: cov.	c.e.
1	Manila	750/4[1]	6	4	102	94	28.4*	3.0	7427	6410
2	Manila	750/4	5	3	76	64	16.7*	2.6	544	3218
3a	Nylon	400/3	6	$4\frac{1}{4}$	108	103	39.1*	3.8	2539	1374
3b	Nylon	400/3	3			103	38.6*	3.7	4428	1453
4a	Nylon	400/3	7	$3\frac{1}{2}$	89	85	29.8*	3.5	2626	2896
4b			10			82	27.7*	3.4	3284	3400
5	Nylon	400/3	4	$2\frac{1}{2}$	63	54	17.5*	3.2	216	2115
6	Cotton	72 thread	4	$4\frac{1}{2}$	114	96	32.4*	3.4	3324	2892
7	Cotton	72 thread	6	$3\frac{1}{2}$	89	73	19.9*	2.7	1514	5126
8	Cotton	72 thread	3	$2\frac{3}{4}$	70	60	19.4*	3.2	631	3480
9	Cotton	72 thread	2	2	51	40	9.8*	2.5	37	221
10	Cotton	(cov) 21 thread	3	$1\frac{1}{2}$	38	35	9.3*	2.7	21	45
11	Manila	(dbl) 650/4	4	6	152	115	38.7*	3.4	704	119

1) Signifies twine made of four strands, each of 750 per pound runnage.

The relation between the 50% point and mesh size is not linear, as is the case with haddock and many other species, and in fact the selection factor increases with increasing mesh size (Fig. 65). The relationship of mesh size and selection factor is consistent for the manila and nylon codends, but the points for cotton vary considerably. The low selection factor for the 73 mm codend may be explained by the masking effect of the cover which was later eliminated by altering the gear, as previously mentioned. No explanation can be provided at present for the high selection factor for the 60 mm codend.

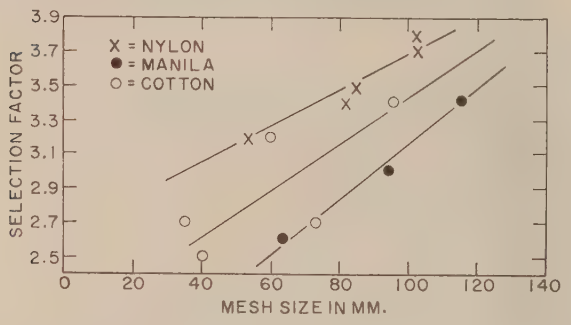

Fig. 65. Selection factor and mesh size for each codend tested.

The lines fitted to all the data for the three net materials tend to converge toward the higher mesh sizes. A theoretical point of equivalent escapement for all three materials is reached where the three lines would, if extrapolated on a straight line basis, intersect at a mesh size of about 180 mm and selection factor of 4.6. The maximum escape factor (girth factor times two) for silver hake is 4.8.

Flexibility differences may be involved in the increase in selection factor with increase in mesh size. The flexibility of the whole mesh, apart from that of the twine itself, can be assumed to increase with increase in mesh size; the longer the scope between knots the more flexible the mesh unit will tend to be. Thus the increasing selection factor for each type of twine may be owing to increasing flexibility of the mesh as a whole.

In addition to the flexibility of the twines there are differences in their frictional characteristics which one would expect to have some effect. The smooth nylon twine, for instance, should offer the least frictional resistance to the passage of fish.

Discussion

If our assumptions about twine flexibility are to be valid, then fish of the critical escape sizes must actually contact the netting in their escapement; otherwise the flexibility (or frictional) effects would not be important. We can further speculate that if our assumptions about flexibility of the whole mesh are valid, the fish must have been forcing their way through meshes. Meshes of the greatest flexibility would, of course, yield most easily to their efforts, and escapement would be greater.

This effect would be most pronounced in meshes which were of a shape not optimal for the escapement of silver hake. The relationship between fish shape and mesh shape has been developed in another paper of this series (pp. 61 to 62) for several species through means of the mesh index which relates body cross-section of the fish to the shape of the mesh. Where the two correspond most closely in shape the mesh index is highest. Partially closed meshes would give a low mesh index for silver hake because of their roundish bodies.

The small net and slow towing speed of the *Priscilla V* would both lend to a low passage of water through the codend mesh, and we might expect the meshes to be more closed than in a larger net being towed faster. This would result in reduced escapement. The limited results of the *Albatross III* with a larger net and faster towing speed (circa 4 knots) do, in fact, suggest that this was the case.

The silver hake taken by the *Albatross III* were too small to permit determination of a firm 50% point, although the data suggest a selection factor of at least 3.8 for the 123 mm double mesh used. A selection factor estimated from the *Priscilla V* results for manila mesh of the same size would be only 3.5. Something more definite could be determined, however, if we knew the exact mesh shape of the codends under tow.

We do have some limited observations of mesh shape in codends under tow. Underwater

camera shots of the *Priscilla V* Series 7 cotton codends indicate mesh angles of 25°-30° at a speed of less than 1 knot. The angle would certainly be larger at the normal towing speed of about 2½ knots. Underwater television studies conducted with a double manila codend under tow by the *Albatross III* at 2½ to 3 knots indicate an average mesh angle of 62° at 2½ to 3 knots and 75° at 4 knots.

An assumed mesh angle of 70° gives a mesh index for silver hake of .89. Adjusting the escape factor with these figures gives a figure of 4.3 which is a measure of the maximum escapement which could occur without distortion of fish or mesh. A mesh angle of 47° would provide the lowest selection factor; i.e., the 2.5 found for the 40 mm cotton codend. A mesh of this twine thickness and small size has a minimum flexibility and probably does not permit much distortion by the escaping fish, and escape would be most closely related to the mesh shape under tow for this codend. We might, therefore, assume that the mesh angle of the *Priscilla V* codends at the normal towing speed of 2½ knots would be about 47° or perhaps only slightly less. The various mesh angles mentioned are demonstrated in Figure 66.

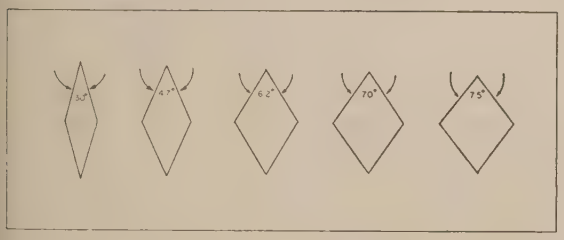

Fig. 66. The shape of meshes having various angles.

If the angle of the *Priscilla V* codend mesh was normally about 47° at normal towing speed (it was 25° to 30° at 1 knot), a selection factor of only 2.5 could be obtained without distortion. For factors as high as 3.8, observed for nylon, a considerable distortion of the mesh would be required. The more flexible twines would, of course, yield more easily and permit a higher escapement. This distortion would also be more easily achieved in the larger meshes. This would, as previously mentioned, explain the relation of selection factor to both twine type and mesh size. The convergence of the lines of Figure 1 at mesh size of 180 mm suggests that at this size maximum distortion is permitted for all of the materials tested and twine flexibility, *per se*, is no longer important.

Another factor that would cause the effect we have noticed is that the mesh might open wider of itself in the lighter twines and in the bigger meshes of any twine. This is only a matter for conjecture, but it does seem possible that such an effect could take place. This might come about through the lessened resistance of the netting to the water with the lighter, smoother twines and with the larger meshes of a given twine.

Some further results of interest concerning the effect of twine flexibility are gained from a special experiment with a wire mesh codend (pp. 58 to 60). The stiffness of the wire held the mesh to nearly optimal shape for escapement of silver hake (mesh index = .99). We would thus expect to find maximum escapement for this mesh which would neither require nor permit distortion for easy passage. The escapement, compared with that of manila, was actually much reduced at the sizes below the 50% point but much increased beyond it, giving a dull selection curve. Although no explanation could be given for the low escapement below the 50% point, the higher escapement beyond it may very well be due to the optimal shape of the wire meshes.

I. ESCAPEMENT OF REDFISH THROUGH CODEND MESHES

Abstract

Experiments with covered codends of double manila twine were carried out with two types of trawls (large and small) to investigate their selectivity for sizes of redfish. The resulting selection factors of 2.2 to 2.6 did not differ with size of net.

The relation of catch size to escapement was investigated without conclusive results.

Meshing of redfish occurred, but not to the extent of hampering the fishing operation. The meshing records indicated that most redfish escape from the last one-third of the codend.

Investigations of the escapement of redfish through meshes of codends were carried out aboard the commercial dragger *Priscilla V* in November 1954 and the research vessel *Albatross III* in May 1956 (Cruise No. 64).

Gear and Methods

All codends used were of double manila twine. The trawl used by the *Priscilla V* was the standard No. 35 manila groundfish trawl. The trawl used by the *Albatross III* was the standard No. 41 Yankee manila trawl. The standard covered codend method was used in all cases. The results of replicate tow experiments, also carried out on this cruise (*see* p. 54), indicated that reliable results could be obtained for redfish selection with covered codends. Records of fish caught by the meshes ("meshed") were kept for all tows in order to investigate the objection that excessive amounts of meshing would occur when using large mesh.

Escapement Results, *Priscilla V*

In three series of tows with double manila codends very few fish were taken, and the results are therefore of limited usefulness. The operations may be summarized as follows:

Series	Mesh Size mm	50% Points cm	Selection Factor	No. of Hauls	Number of fish in c.e.	cov.
I	115	28.2*	2.5	8	396	507
II	99	24.0*	2.4	3	162	923
III	69	15.8*	2.3	4	147	124

A summary of numbers of fish of each length caught in the codend and cover for each series is given in Table F-65. The selection curves are shown in Fig. 67.

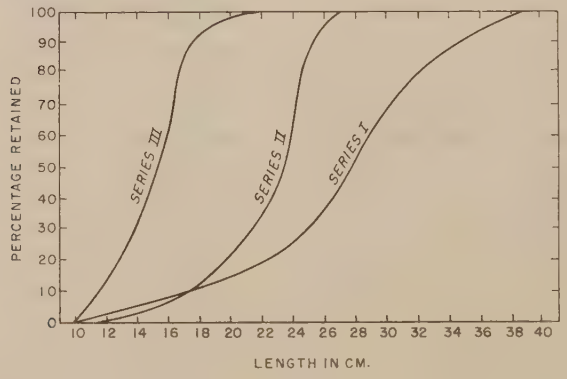

Fig. 67. Selection curves for *Priscilla V*; double manila codends of Series I (115 mm), Series II (99 mm), and Series III (69 mm).

"Albatross III" **Cruise No. 64.**

Three series of tows with double manila codends were carried out with the catches varying from small to very large. The numbers of fish of each length taken in the codend and cover are given in Tables F-66, 67 and 68. The operations may be summarized as follows:

Series	Mesh Size mm	50% Point cm	Selection Factor	No. of Hauls	Number of fish in c.e.	cov.
I	132	31.6*	2.4	2	360	1625
II	109	23.6*	2.2	8	7455	7620
IIIa	80	17.7*	2.2	4	4713	370
IIIb	82	21.3*	2.6	3	567	643

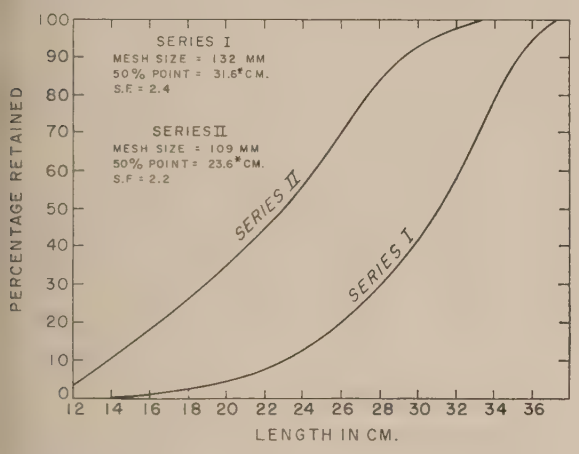

Fig. 68. Selection curves for *Albatross III* No. 64; double manila codends of Series I (132 mm), and Series II (109 mm).

The selection curves for Series I and Series II. plotted in Figure 68, yield selection factors of 2.4 and 2.2, respectively. These low selection factors may be expected of such deep-bodied and spiny fish.

The results of Series III have been divided into two sections; IIIa, Western Nova Scotian Banks, and IIIb, Gulf of Maine. The results for the two areas differed, although the codend was the same in both cases, the only difference being an increase of 2 mm in mesh size. The selection curves for the two series, shown in Figure 69, indicate a greater increase in escapement than the 2 mm difference in mesh size would lead us to anticipate. This difference is associated with a change in location, length composition, and size of catch. Which, if any, of these factors were causative cannot be inferred.

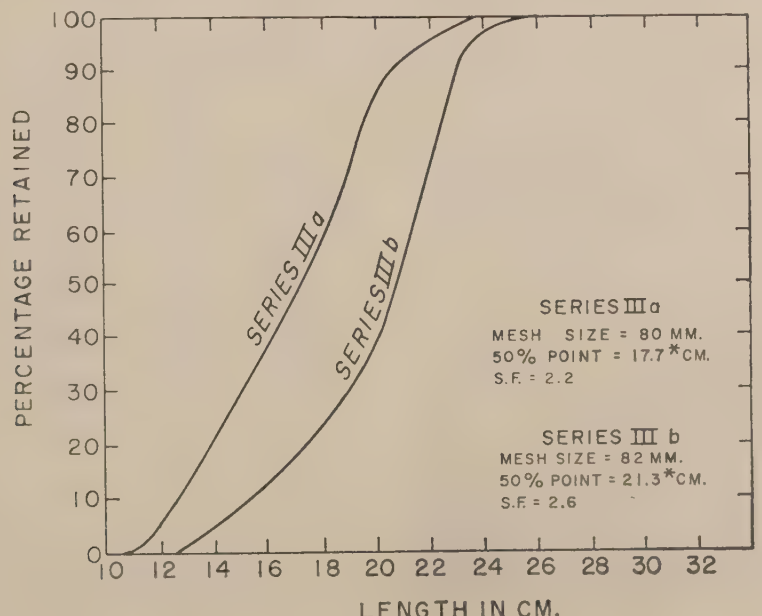

Fig. 69. Selection curves for *Albatross III* No. 64; double manila codends of Series IIIa (80 mm) and Series IIIb (82 mm).

Selection experiments with other species (*e.g.* haddock) have shown that catch size is inversely related to escapement. Therefore, we have plotted, in Figure 70, the 50% points against the numbers of redfish caught on individual tows in Series IIIa and IIIb. Escapement appears to be related to the size of the catches to some extent.

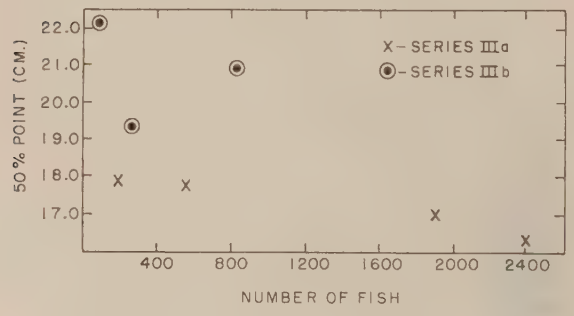

Fig. 70. Number of redfish per tow and 50% points for Series IIIa and IIIb.

The numbers per tow and 50% points for Series II, plotted in similar manner in Figure 71, show no relationship. The large tows of 1,243 and 9,811 fish have the same amount of escapement as the smaller tows of 262 and 449 fish.

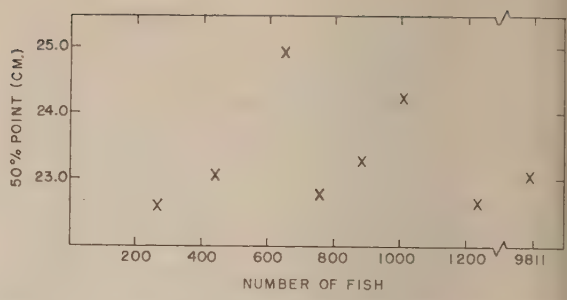

Fig. 71. Number of redfish per tow and 50% points for Series II.

The two tows of Series I of 1,405 and 580 fish gave similar 50% points, indicating no effect of catch size.

Meshing Results, *Priscilla V*

In Series I, 38 fish were meshed in the 115 mm codend. This is less than 7% of those which escaped into the cover. Very few were meshed in the other series.

Meshing Results, *Albatross No. 64*

Meshing was slight in all series: none were meshed in Series I; 43 in Series II; 90 in IIIa; and 17 IIIb. The greatest amount of meshing thus occurred in Series IIIa where it amounted to less than 25% of the total number in the cover.

TABLE 8. Numbers of fish gilled in Series IIIa.

Length cm	Number of Fish meshed in Codend by Zone								Total in c.e.	Total in cov.	Total fish taken	Percentage in cover	Percentage Meshed
	1	2	3	4	5	6	7-9	All Zones					
18		3						3	24	32	59	54.2	5.1
19		2	1					3	43	42	88	47.7	3.4
20	1	4	2					7	75	26	108	24.1	6.5
21	1	4	2	3	1	1		12	92	20	124	16.1	9.7
22	3	9	3	3	1			19	180	12	211	5.7	9.0
23	7	10	3	2	1			23	227	7	257	2.7	8.9
24	5	4	1	2		1		13	232	3	248	1.2	5.2
25	1	4	2	1				8	216	1	225	0.4	3.6
26			1					1	153	3	157	1.9	0.6
27		1						1	135		136	0.0	0.7
TOTAL	18	41	15	11	3	2	–	90					
Accum. Percent	20	66	82	94	98	100	100						

The codend in Series IIIa was divided into 9 lateral zones of 8 rows of meshes each, numbered 1 to 9 from the after end forward. In Table 8 we have listed the number of fish of each length meshed in the various zones of the codend, and for comparison the numbers of each length taken in the codend and cover over the range of sizes of fish that were meshed. Table 1 shows that the percentage of redfish of various lengths meshed in the codend reaches a peak of 9.7% at 21 cm where only 16.1% were escaping into the cover. Fewer fish are meshed at the lower lengths where more fish escape and also at the higher lengths where fewer fish escape.

In the three after zones, 82% were meshed, 18% in the three central zones, and none in the forward zones. We have shown in another section (p. 37) that over 80% of haddock which escaped did so through the after quarter of the codend. These meshing results suggest that redfish also escape mostly through the after end of the codend.

Summary and Discussion

The selection factors of 2.3 to 2.5 obtained from the *Priscilla V* experiments were confirmed by the selection factors of 2.2 to 2.6 obtained from the *Albatross III* experiments. The two entirely different fishing units and gear types thus produced similar results. We may tentatively conclude, although the data are sparse, that net type, overall size of the codend, speed of tow, and other related factors have limited effect, and that the most important factor influencing redfish escapement is mesh size.

Our results agree with the selection factor of 2.3 found by McCracken (p. 149) for the Gulf of St. Lawrence. Templeman (p. 204), working on Newfoundland Banks, obtained selection factors ranging from 2.1 to 2.7 which do not disagree with ours but merely extend the range. Our meshing results also agree with Templeman's in that the quantities involved were, in general, slight and meshing did not create any operational difficulties.

It would appear from the *Priscilla V* results that mesh size and 50% point are not linearly related, since the selection factor increases with increasing mesh size; *i.e.*, from 2.3 for 69 mm mesh to 2.5 for 115 mm mesh. This is probably an artifact, however, as it is not borne out by the more extensive *Albatross III* results. Nor do Templeman's results show a relationship between selection factor and mesh size. This matter would, nonetheless, bear further investigation.

J. EFFECT OF THE GEORGES BANK MESH REGULATION: SELECTIVITY AND FISHING POWER OF LARGE MESH OTTER TRAWLS

Abstract

A comparison is made of the catches of Georges Bank haddock trawlers with the $4\frac{1}{2}$ inch regulation mesh and the $2\frac{7}{8}$ inch pre-regulation mesh for the period 1954-1956. The regulation mesh caught 8% more large haddock and 19% less scrod haddock than the preregulation mesh. A selection factor of 3.3, calculated from the length compositions of the catches, agrees with that predicted from experimental results.

Introduction

The first management recommendation made by the International Commission for the Northwest Atlantic Fisheries following its inception was for a minimum mesh size of $4\frac{1}{2}$ inches (114 mm.) for otter trawls used in the Subarea 5 haddock fishery (Graham 1952). The recommendation was subsequently approved by all member nations and became effective as a regulation in June 1953.

Only the United States fishes extensively in Subarea 5 and *within this subarea* takes about 90% of its haddock catches on Georges Bank (5Z). A control plan was established for the Georges Bank fishery to permit assessment of the effectiveness of the regulation. Under this plan a group of large trawlers from Boston, varying in number from four to eight, was licensed to fish with the pre-regulation small mesh. Comparison of the records of this control group with

those of the regulated vessels was expected to demonstrate the effectiveness of the regulation.

The change-over to the regulation mesh for the Georges Bank trawlers took place over a period of several months. Our information indicates that the conversion was completed and all regulated vessels were using large mesh by the end of 1953. The Georges Bank fishery is carried out for the most part by a fleet of about 47 large otter trawlers of 150-300 gross tons (OTL's) (*see* Fig. 72). The vessels all use the standard "No. 41 Yankee" trawl and generally fish the various parts of Georges Bank in company with one another in such a manner as to distribute their effort similarly with respect to gear, time, and area.

Fig. 72. A typical Georges Bank large otter trawler.

Comparisons of catches per day and lengths of haddock taken with regulation size and pre-regulation size ($2\frac{7}{8}$ inches, 74 mm) meshes have been published previously by Graham (1954) Graham and Premetz (1955) and Clark (1955). These studies indicated that the $4\frac{1}{2}$ inch mesh was releasing many of the smaller sizes, and that it was probably operating at a higher efficiency for sizes above the selection range. However, the methods of analysis were not sufficiently refined to express these differences in quantitative terms.

It is the purpose of this study to determine, from differences in catch per unit effort of pre- and post- regulation mesh sizes for various sizes of haddock, the selectivity and the relative fishing power of the $4\frac{1}{2}$ inch mesh. To make these determinations required the use of analytical methods which differ from those of the earlier studies mentioned above. The basic difference is in the derivation of comparable effort statistics.

Data Sources and Methods

The data were provided by routine interview and catch sampling activities at New England landing ports, primarily Boston where each vessel captain is interviewed upon arrival to obtain information upon area fished and effort expended. This information together with landings records provided us with the information required to determine catch per unit of effort for each vessel. The period of study is calendar years 1954, 1955, and 1956.

The routine sampling program at New England ports yields an extensive collection of length measurements of Georges Bank haddock (30,000 fish per year). These data were used to determine the length compositions of landed haddock for each mesh size category. A concurrent sampling program aboard the trawlers provided estimates of the length composition of haddock discarded at sea.

Codends of the Georges Bank trawlers were measured regularly at Boston through the period of study. The mesh sizes used represent the average for the whole upper side of the codend (usually 44-50 meshes in length). The Georges Bank OTL's invariably use bull hide protectors on the undersides of their codends. The codends are normally made of a single layer of netting with no protective material on the upper side. The twine used for the large mesh codends during the period of study was invariably 50/4 manila, double. Tow duration is normally 80 minutes.

To provide for direct comparisons between small- and large-mesh fleets, it is necessary to express the records in terms of catches per unit of effort. We did this in terms of the average catch per day's fishing.

The catch per day for each fleet was determined for each quarter by averaging the quarterly catches per day of the individual vessels after adjusting each to a standard fishing power. This adjustment was made by multiplying each vessel's catch per day by the reciprocal of its "efficiency

factor", as listed in Table 9. Differences in fishing power of the vessels are thus compensated by adjustment to a theoretical standard fishing power. The necessity for such an adjustment is shown by the variation in efficiency factors from a low of 0.74 to a high of 1.55. The inclusion of either of these extremes in the small group of four to eight small mesh vessels would, of course, greatly influence its fishing power and average catch per day.

The catch per day values computed in the above manner are in terms of landed weight of gutted fish in the market categories of "large" and "scrod."[3] The weights were converted to numbers of fish of each length caught per day (from the length data derived from the sampling mentioned previously) by the small and large mesh fleets. The average numbers of each length discarded per day (from sampling at sea) were added to those landed to obtain the final estimates for each quarter.

Results

The catch per day (landings only) averages for the small and large mesh fleets for each quarter over the three-year period are given in Table 10. The small mesh vessels landed more scrod per day than large mesh vessels in every quarter except January-March 1954, when catches per day were generally poor and the two fleets landed equal amounts. A reverse, although less consistent, situation is shown for large haddock: large mesh outfished small mesh in the majority of quarters (7 out of 12, one equal). Large haddock are mostly over 48 cm and thus beyond the effective selection range of the large mesh.

The average catches per day of large haddock for the full three-year period (5,300 pounds for large mesh, 4,900 pounds for small mesh) show the large mesh to have an average of about 8% greater fishing power for large haddock. The average catch per day of scrod haddock for the three years (7,600 pounds for large mesh, 9,400 pounds for small mesh) shows the large mesh to have 19% lesser fishing power for scrod haddock.

The increased catches of large haddock by the large mesh fleet may reflect an increased efficiency of the large mesh gear. This could come about through improved hydrodynamic properties of the trawl, resulting perhaps from better straining action or greater distance towed because of the lowered resistance of the net. The former appears the more likely as we have observed (*see* p. 65) that in trawls of given specifications those modified only to the extent of having large mesh in the codend do not tow measurably faster than those with small mesh codends. We have observed on another occasion (*see* p. 41) that a trawl constructed wholly of very small mesh offers much more resistance than one of large mesh and consequently tows more slowly. The regulation required only a change in the codend and a small section of the after belly of our Georges Bank otter trawlers, other parts of the trawls have always been made of large mesh. This small alteration does not appear to be sufficient to alter the towing speed of the net significantly. We are thus led to believe that the increased catches come about from improved hydrodynamic properties of the net or other, indeterminant, factors rather than from increases in towing speed.

There is another entirely different factor which could cause the same effect; *viz.*, the large mesh vessels making lower catches of scrod than small mesh vessels would direct their efforts toward concentrations of larger fish. This might mean shifting only a few fathoms in depth or a few hundred yards in distance. It is not possible to isolate this factor from present data. Nor have our attempts to measure its influence by studying fleet distributional patterns met with success.

However, other experiments, involving vessels with large and small mesh fishing side by side, have shown evidences of greater fishing power for large mesh. Davis (1934), for example, demonstrated an approximate 17% increase in catches of haddock beyond the selection range with large mesh in a well controlled experiment involving two vessels fishing for several months in close proximity. Our Pairtows I studies (p. 41), with two large trawlers fishing within a few hundred feet of each other, also show large mesh to operate at a higher efficiency than small mesh.

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[3]) Haddock fishermen separate their catches at sea into official market categories of large (over 2½ pounds) and scrod (1½ to 2½ pounds). Fish smaller than 1½ pounds are often landed and included in the scrod.

TABLE 9. Efficiency factors for vessels by year and the average for all years.

Vessel	1954	1955	1956	Average
0275	1.25	1.28	1.40	1.31
0300	1.10	.94	.89	.98
0385	1.13	.79	.92	.94
0480	1.21	1.22	1.02	1.15
0490	.92	.71	.84	.82
0495	1.08	.89	.90	.96
0500	1.20	.96	.93	1.03
0525	1.10	1.15	1.06	1.10
0560	1.06	1.31	1.25	1.21
0790	.85	.62	.80	.76
1270	1.56	1.55	1.55	1.55
1590	.94	.97	.98	.96
2165	1.11	.84	1.42	1.12
2480	1.13	1.00	1.05	1.06
2760	.62	.86	.73	.74
2845	1.34	1.05	1.03	1.14
2880	.99	.95	1.08	1.01
2910	.77	.75	.74	.75
3045	1.36	1.37	1.37	1.37
3145	.72	.76	.92	.80
3020	.94	.89	.95	.93
3150	.68	.79	.89	.78
3195	.88	.72	.90	.83
3710	.94	.85	.79	.86
3740	.75	.76	.78	.76
3785	.89	.81	.75	.82
4005	.93	.90	1.02	.95
4065	.95	1.00	.88	.94
4075	1.15	1.08	1.01	1.08
4090	.99	1.22	1.09	1.10

TABLE 10. Catch per day for Georges Bank large otter trawlers in thousands of pounds landed.

	Large Haddock				Scrod Haddock			
	Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec.	Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec.
1954:								
Large mesh	7.6	5.1	2.9	3.1	2.8	9.8	15.6	8.6
Small mesh	5.4	3.9	2.5	3.6	2.8	14.1	19.3	10.1
1955:								
Large mesh	7.1	6.1	4.3	4.7	4.0	8.3	11.8	4.6
Small mesh	7.3	6.3	4.3	3.9	6.2	9.8	16.0	5.2
1956:								
Large mesh	8.2	7.2	3.7	3.8	5.3	6.0	9.0	5.7
Small mesh	8.4	6.3	2.9	3.1	6.1	7.1	9.8	6.6
Quarterly Averages:								
Large mesh	7.6	6.1	3.6	3.9	4.0	8.0	12.1	6.3
Small mesh	7.0	5.5	3.2	3.5	5.0	10.3	15.0	7.3
3-year Average								
Large mesh		5.3				7.6		
Small mesh		4.9				9.4		
Percentage difference		+8.2%				−19.1%		

The lower catches of scrod for large mesh, on the other hand, may be easily explained by escapement through the meshes. To determine the size of fish passing through the meshes we compared the catches per day of each length by the small and large mesh trawlers. For simplicity of presentation the length data have been summarized by quarter for all three years and presented as the average numbers of each size caught (both landed and discarded) per day fished. These data are given in Table F-69 and plotted as length frequency polygons in Figures 73-77.

Examination of the polygons shows (from the greater catches of the small mesh) that selection was operating for large mesh below about 50 cm. Greater numbers of fish beyond the selection range (*i.e.* greater than 50 cm) were taken by the large mesh in all quarters (from 103-114% of small mesh catches). The average value of 108% for all quarters confirms our previous estimate of an 8.2% increased efficiency for large mesh based on landings in pounds of the market category "large."

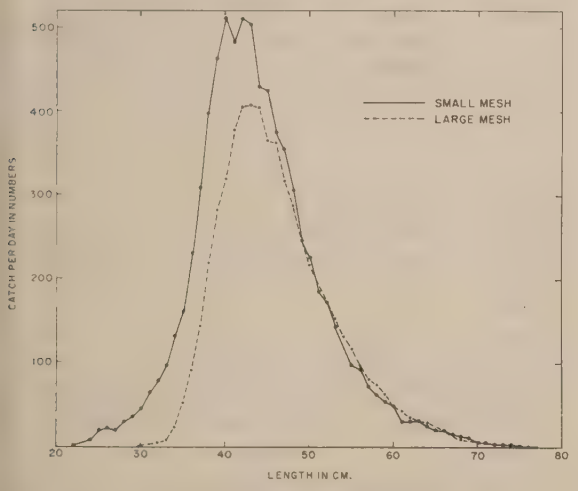

Fig. 73. Length composition of small and large mesh catches, average for all quarters.

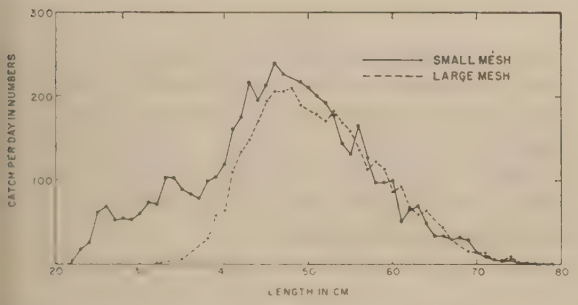

Fig. 74. Length composition of small and large mesh catches, January - March.

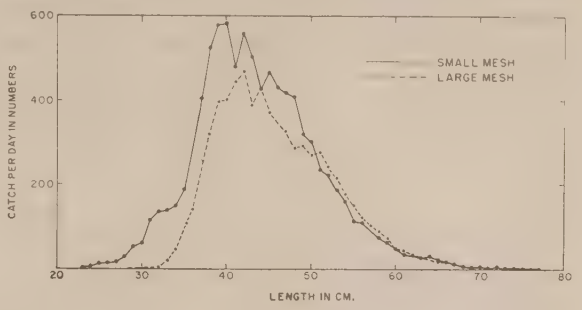

Fig. 75. Length composition of small and large mesh catches, April - June.

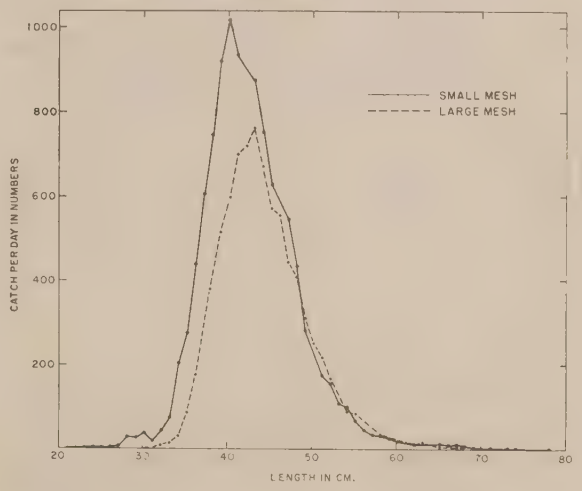

Fig. 76. Length composition of small and large mesh catches, July - September.

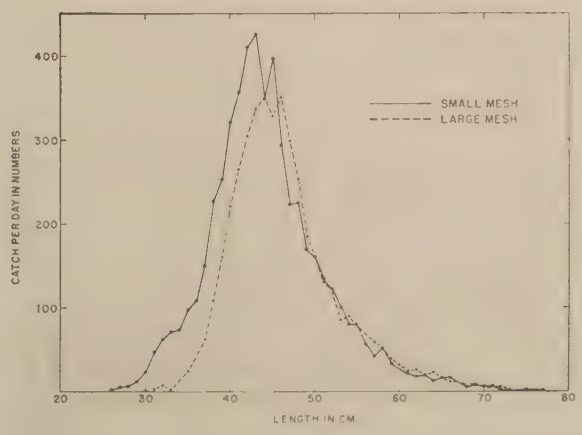

Fig. 77. Length composition of small and large mesh catches, October - December.

These data on numbers caught per day can also be expressed as selection curves in the manner of a replicate tow experiment. We have plotted, from the percentages given in Table F-69, selection curves for each quarter and for the full three-year period. These are presented in Figures 78-82. The curves are of the sigmoid type usual to mesh selection studies and, although considerable variation is evident, reliable 50% retention points may be estimated. These vary from 36.5* to 39.6* cm with an average for all quarters of 37.9* cm.

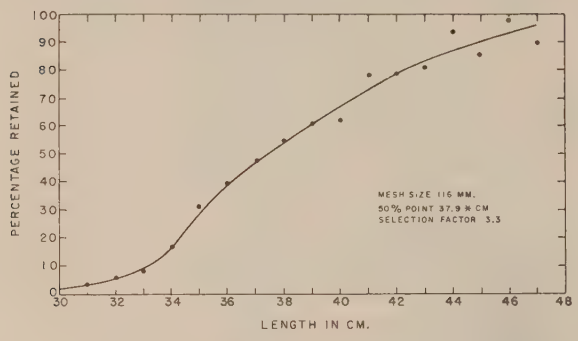

Fig. 78. Selection curve for all quarters. Mesh size 116 mm, 50% point 37.9 cm, Sel. F. 3.3.

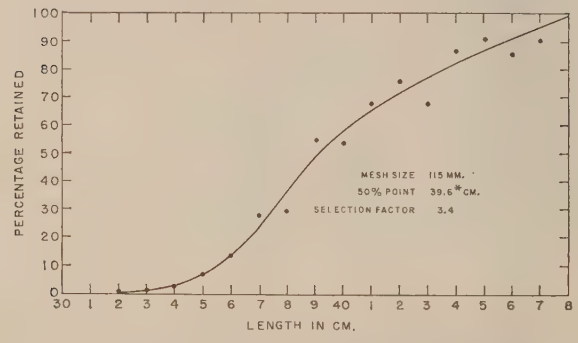

Fig 79. Selection curve for January - March quarter. Mesh size 115 mm, 50% point 39.6 cm, Sel. F. 3.4.

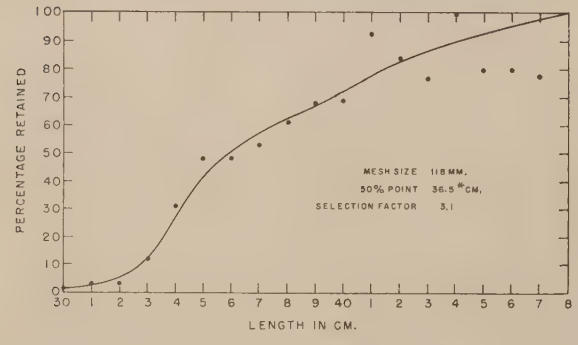

Fig. 80. Selection curve for April - June quarter. Mesh size 118 mm, 50% point 36.5 cm, Sel. F. 3.1.

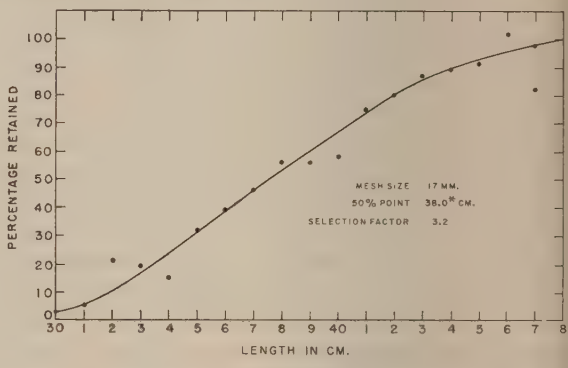

Fig. 81. Selection curve for July - September quarter Mesh size 117 mm 50% point 38.0 cm, Sel F. 3-2.

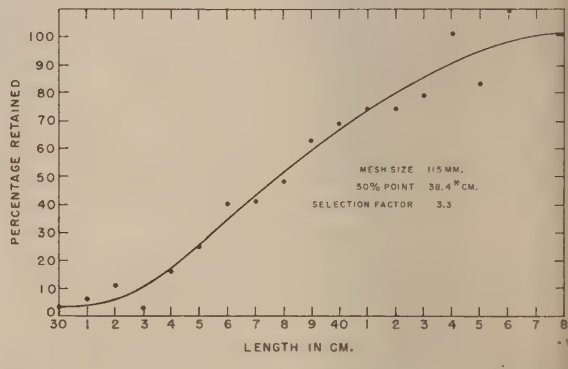

Fig. 82. Selection curve for October - December quarter. Mesh size 115 mm, 50% point 38.4 cm, Sel. F. 3.3.

We had predicted a 50% point of 37.5 cm for the regulation, 114 mm, mesh on the basis of a selection factor of 3.3 (Graham 1952). The regulation mesh in actual practice, however, varied from 115 to 118 mm for the various quarters, as may be seen from the following tabulation of average mesh sizes:

	January to March		April to June		July to September		October to December	
	in	mm	in	mm	in	mm	in	mm
1954	4.56*	116	4.50	114	4.44	113	4.35	110
1955	4.55*	116	4.75	121	4.68	119	4.65	118
1956	4.49	114	4.70	119	4.65	118	4.64	118
Average	4.53	115	4.65	118	4.59	117	4.54	115

*partially estimated

We would then expect a 50% point somewhat higher than that predicted on the basis of a 114 mm mesh.

The selection factors varied from 3.1-3.4 and averaged 3.3 (the predicted selection factor) for the whole period.

Summary

Otter trawlers using the regulation size mesh on Georges Bank landed about 8% more large haddock and 19% less scrod haddock than small mesh control vessels.[4] Their codends averaged 116 mm in mesh size, about 2 mm larger than required by the regulation (114 mm).

The increase in large haddock catches is probably owing to an increased efficiency of larger mesh gear. The decrease in scrod haddock catches came about through escapement of small haddock.

Selectivity curves were computed which yielded an average 50% point of 37.9* cm. That this is slightly higher than the 37.5* cm predicted is shown to be associated with a slightly higher than required average mesh size. The calculated average selection factor of 3.3 agrees with that predicted for the regulated fishery.

References

CLARK, JOHN R. 1952. Experiments on the escapement of undersized haddock through otter trawls. *U. S. Fish and Wild l. Serv., Comm. Fish. Rev.*, 14(9): 1-7.

CLARK, JOHN R. 1955. Effect of mesh regulation in Subarea 5. *Ann. Proc., IC NAF*, 1954-55, 5(3A): 63-64.

DAVIS, F. M. 1934. Mesh experiments with trawls, 1928-1933. *Min. Agric. and Fish., Fish. Invest.*, Ser. II, 14(1): 56 pp.

GRAHAM, H. W. 1952. Mesh regulation to increase the yield of the Georges Bank haddock fishery. *2nd Ann. Rept., IC NAF*, 1951-1952, (3): 33 pp.

GRAHAM, H. W. 1954. Conserving New England haddock. *Trans. 19th North Am. Wildl. Conference*: 397-403

GRAHAM, H. W. and E. D. PREMETZ. 1955. First year of mesh regulation in the Georges Bank haddock fishery. *U. S. Dept. Int., U. S. Fish and Wildl. Serv., Spec. Sci. Rept.* 142: *29 pp.*

GULLAND, J. S. 1956. On the selection of hake and whiting by the mesh of trawls. *J. Cons. int. Explor. Mer.*, 21(3): 296-309.

PARRISH, BASIL B. 1950. Experiments to determine the effect of the use of a small meshed cover on the fishing power of the otter trawl. *Comp. Fish. Comm. at ICES 1950.*

List of Tables Including Basic Data

The tables F-1 to F-69, listed below, give detailed data on length measurement of fish from the experiments referred to in the above paper. These Tables – not printed in the paper – are filed with the ICNAF Secretariat, from where they can be requested for reference.

F - 1. Haddock catches in 123 mm codend with full cover (series I); 5,097 spec.

F - 2. Haddock catches in 123 mm codend with 22 mesh (series II), 16½ mesh (series III) and 11 mesh (series IV) cover; 1,766 spec.

F - 3. Haddock catches with full cover and half cover; 22,439 spec.

F - 4. Summary of catches of haddock from "with hides" tows and "without hides" tows for double manila codend (series I); 4,070 spec.

F - 5. Summary of catches of haddock from "with hides" tows and "without hides" tows for double manila codends (series II); 6,270 spec.

F - 6. Summary of catches of silver hake in codend, upper and lower cover, and percentages retained, for *Priscilla V*; 5,881 spec.

4) The escapement of 19% of the scrod—or 13% of the total catch—produces the beneficial effect of the mesh regulation. Even after natural mortality a gain of 8% might be expected.

F - 7. *Albatross III.* Total catches of haddock and belly cover (full) catches, series I – 21,454 spec., series II – 19,221 spec.

F - 8. *Priscilla V.* Total catches and belly cover catches of silver hake, 11,925 spec.

F - 9. Numbers of haddock of each length taken by the *Albatross III* (5,122 spec.) and *Delaware* (4,364 spec.) in standardization tows, group I.

F - 10. Numbers of haddock of each length taken by the *Albatross III* (7,103 spec.) and *Delaware* (7,073) spec.) in standardization tows, group II.

F - 11. Numbers of haddock of each length taken by the *Albatross III* (6,632 spec.) and *Delaware* (7,543 spec.) in paired tows, series II.

F - 12. Numbers of haddock of each length taken by the *Albatross III* (5,869 spec.) and *Delaware* (6,257 spec.) in paired tows, series III.

F - 13. Numbers of haddock of each length taken by the *Albatross III* (10,790 spec.) and *Delaware* (7,185 spec.) in paired tows, series IV.

F - 14. Numbers of haddock of each length taken by the *Albatross III* with 120 mm (port) (4,648 spec.) and 55 mm (starboard) (4,489 spec.) trawls.

F - 15. Comparison of sizes of silver hake caught by 57 mm (4,749 spec.) and 84 mm (2,643 spec.) mesh cotton nets.

F - 16. *Michigan*, No. 1, catches of haddock with covered (5,990 spec.) and uncovered (6,167 spec.) codends.

F - 17. *Michigan*, No. 2, catches of haddock with covered (2,861 spec.) and uncovered (3,026 spec.) codends.

F - 18. *Albatross III*, No. 51, catches of haddock with covered (15,369 spec.) and uncovered (19,888 spec.) codends. Series I and II.

F - 19. *Albatross III*, No. 52, catches of haddock with covered (2,977 spec.) and uncovered (3,557 spec.) codends.

F - 20. Catches of haddock with covered (305 spec.) and uncovered (73 spec.) codends, pairtows I, series I.

F - 21. Catches of haddock with covered (215 spec.) and uncovered (50 spec.) codends, pairtows I, series II.

F - 22. *Priscilla V*, catches of silver hake with covered (4,515 spec.) and uncovered (3,341 spec.) codends, series I.

F - 23. *Priscilla V*, catches of silver hake with covered (2,896 spec.) and uncovered (1,898 spec.) codends, series II.

F - 24. *Priscilla V*, catches of silver hake with covered (3,570 spec.) and uncovered (3,700 spec.) codends, series III.

F - 25. *Albatross III*, No. 64, catches of redfish with covered (3,416 spec.) and uncovered (3,287 spec.) codends.

F - 26. Series I, catches of haddock in a 113 mm double manila codend and cover for various tow intervals (all tows with hides); (4,419 spec.)

F - 27. Series II, catches of haddock in a 123 mm double manila codend and cover for various tow intervals (tows 6-32 with hides, tows 41-50 without hides); 15,626 spec.

F - 28. Series III, catches of haddock in a 73 mm double manila codend and cover for various tow intervals (tows 18-34 with hides, tows 35-40 without hides); 14,302 spec.

F - 29. Haddock caught in wire mesh codend (632 spec.) and cover (185 spec.).

F - 30. Silver hake caught in wire mesh codend (1,188 spec.) and cover (1,170 spec.).

F - 31. Number of silver hake of each size in codend and cover of normal tows and shark tow; 3,733 spec.

F - 32. Catches of haddock in paired tows of *Delaware* and *Albatross III* with manila codends of 56 mm and 59 mm mesh (phase I); 6,613 spec.

F - 33. Catches of haddock in paired tows of *Albatross III* and *Delaware* with double manila codends of 59 and 119 mm mesh (phase II); 8,194 spec.

F - 34. Catches of haddock in paired tows of the *Delaware* and *Albatross III* with single cotton codends of 57 and 144 mm mesh (phase III); 2,167 spec.

F - 35. Catches of haddock in paired tows of *Albatross III* and *Delaware* with single cotton codends of 106 and 58 mm mesh (phase IV); 8,557 spec.

F - 36. Catches of haddock in paired tows of *Albatross III* and *Delaware* with single cotton codends of 111 and 86 mm mesh (phase V); 6,048 spec.

F - 37. *Michigan* series I, catches of haddock in cover (405 spec.) and codend (10,465 spec.) with 92 mm mesh of 50/4 double manila.

F - 38. *Michigan*, series II, catches of haddock in cover (955 spec.) and codend (4,103 spec.) with 98 mm mesh of 50/4 double manila.

F - 39. *Michigan*, series III, catches of haddock in cover (3,684 spec.) and codend (10,285 spec.) with 105 mm mesh of 50/4 double manila.

F - 40. *Wisconsin*, series I, catches of haddock in cover (3,069 spec.) and codend (8,179 spec.) with 109-114 mm mesh of 50/4 double manila.

F - 41. *Wisconsin*, series II, catches of haddock in cover (1,470 spec.) and codend (1,640 spec.) with 121 mm mesh of 50/4 double manila.

F - 42. *Albatross III*, No. 51, series I, catches of haddock in cover (2,004 spec.) and codend (1,643 spec.) with 107 mm mesh of 45/4 double manila.

F - 43. *Albatross III*, No. 59, series I, catches of haddock in cover (3,065 spec.) and codend (2,435 spec.) with 140 mm mesh of 45/4 double manila.

F - 44. *Albatross III*, No. 59, series II, catches of haddock in cover (2,564 spec.) and codend (1,961 spec.) with 154 mm mesh of 45/4 double manila.

F - 45. *Albatross III*, No. 59, series III, catches of haddock in cover (2,294 spec.) and codend (1,153 spec.) with 167 mm mesh of 45/4 double manila.

F - 46. *Albatross III*, No. 74, series I, catches of haddock in cover (2,106 spec.) and codend (4,619 spec.) with 127 mm mesh of Dacron.

F - 47. *Albatross III*, No. 74, series II, catches of haddock in cover (2,831 spec.) and codend (2,378 spec.) with 105 mm mesh of nylon (cargo netting).

F - 48. *Albatross III*, No. 74, series III, catches of haddock in cover (2,113 spec.) and codend (3,075 spec.) with 134 mm mesh of nylon (cargo netting).

F - 49. *Albatross III*, No. 74, series IVa, catches of haddock in cover (931 spec.) and codend (2,460 spec.) with 122 mm mesh of nylon (cargo netting).

F - 50. *Albatross III*, No. 74, series IVb, catches of haddock in cover (3,259 spec.) and codend (2,143 spec.) with 124 mm mesh of nylon (cargo netting).

F - 51. Numbers of silver hake caught and percentages retained in a 94 mm manila codend; 13,837 spec.

F - 52. Numbers of silver hake caught and percentages retained in a 64 mm manila codend; 3,762 spec.

F - 53. Numbers of silver hake caught and percentages retained in a 103 mm nylon codend; 3,913 spec.

F - 54. Numbers of silver hake caught and percentages retained in a 103 mm nylon codend; 5,881 spec.

F - 55. Numbers of silver hake caught and percentages retained in an 85 mm nylon codend; 6,684 spec.

F - 56. Numbers of silver hake caught and percentages retained in an 82 mm nylon codend; 4,824 spec.

F - 57. Numbers of silver hake caught and percentages retained in a 54 mm nylon codend; 2,331 spec.

F - 58. Numbers of silver hake caught and percentages retained in a 96 mm cotton codend; 6,216 spec.

F - 59. Numbers of silver hake caught and percentages retained in a 73 mm cotton codend; 6,640 spec.

F - 60. Numbers of silver hake caught and percentages retained in a 60 mm cotton codend; 4,111 spec.

F - 61. Numbers of silver hake caught and percentages retained in a 40 mm cotton codend; 258 spec.

F - 62. Numbers of silver hake caught and percentages retained in the 35 mm cotton cover; 66 spec.

F - 63. Numbers of silver hake caught and percentages retained in a 115 mm double manila codend; 725 spec.

F - 64. *Albatross III*, catches of silver hake in a double manila codend of 123 mm mesh size; 1,416 spec.

F - 65. Catches of redfish in *Priscilla V* double manila codends of series 1-115 mm (903 spec.), series II – 99 mm (1,085 spec.) and series III – 69 mm (271 spec.).

F - 66. Catches of redfish in *Albatross III* double manila codend of 132 mm mesh size (series I); 1,985 spec.

F - 67. Catches of redfish in *Albatross III* double manila codend of 109 mm mesh size (series II); 15,075 spec.

F - 68. Catches of redfish in *Albatross III* double manila codend of 80 mm (series III a) and 82 mm (series IIIb) mesh sizes; 6,293 spec.

F - 69. Haddock, average catch per day in numbers of each length for large and small mesh by quarters; 68,656 spec.

North Atlantic Fish Meeting Marking Symposium, Woods Hole, Massachusetts, May 1961. International Commission for the Northwest Atlantic Fisheries, Special Publication No. 4, p. 59-63

10.

Bering Sea King Crab *(Paralithodes Camtschatica)* Tagging Experiments

By

FRED C. CLEAVER*

Introduction

e king crab is found in cold waters of the North ic Ocean, the Bering Sea, and the Okhotsk Sea. ccurs in the eastern Bering Sea where bottom r temperatures are at times below 0° Centigrade, t is not abundant north of 59° North latitude, s generally not the object of fishing north of 58°. her (smaller) species, *P. platypus*, becomes common gher latitudes.

e average size in the commercial catch for rn Bering Sea in 1941 was 7.3 pounds with a mum of about 14 pounds (Wallace, Pertuit and um, 1949). Because only the larger crabs are , this had not changed much by 1960. In the ic Ocean south of the Alaska Peninsula 20-pound mens are frequently found.

hing is done in waters of less than 100 fathoms. 100-fathom contour extends from Unimak Pass e western tip of the Alaska Peninsula in a north- rly direction, passing westward of the Pribilof ds. The bottom becomes gradually shallower to astward and is smooth and free from obstructions. r trawling can be done anywhere with little er of damage to the gear. The bottom of the eastern Bering Sea is a moderately flat, smooth

ost of the catch is taken with large mesh tangle which are highly selective for the larger crabs. irregular shape and many spines of the king crab e them to tangle readily in the nets. Otter ls are also used in the fishery.

e usually covers much of the fishing ground by uary and may remain until late April or early . Fishing with otter trawl gear is possible the e year, but activity has been very limited except ng the late spring and summer months. In recent there has been no winter fishery.

ne fishery for king crab (*Paralithodes camtschatica*) e southeastern Bering Sea was begun by Japan t 30 years ago. Following World War II Japan the United States jointly exploited the stocks, in 1959 and 1960 the Union of Soviet Socialist ublics also engaged in the fishery. Because of er concern over the effect of fishing on this es the International North Pacific Fisheries Commission, of which Canada, Japan and the United States are members, undertook to study the stocks of king crab. The work reported here was done by the United States Bureau of Commercial Fisheries for the Commission with the coöperation of Japan. Japanese scientists have also conducted studies of the king crabs in the eastern Bering Sea as well as in waters near Japan.

The overall purpose of this investigation is to determine the effect of fishing upon the yield of the stock. To accomplish this, studies are being made of various features of the life history of the crab and of the fishery. Much of this is not particularly germane to a discussion of tagging and will not be considered here. The objective of this paper is to examine the design and analysis of tagging experiments in the king crab studies.

The work has been done by a small group at the Seattle Biological Laboratory of the Bureau. From 1956 to 1958 I was directly responsible for the investigations. Mr. Takashi Miyahara, who is now leader of the king crab program, supplied the data that I am using here.

The tagging was designed to study the limits and degree of intermixing of the southeastern Bering Sea king crab population, growth, and rates of mortality. Size frequency data were collected to test the accuracy of the results of the growth analysis. Quantitative trawling was undertaken to provide an alternate method of calculating fishing mortality.

Tagging Methods

The king crab is in some respects a very satisfactory animal for tagging. It is resistant to damage by handling or suffocation and if treated with reasonable care, can be caught at depths of 100 fathoms or more and released in good condition. The commercial fishery commonly takes the crabs in otter trawls, holds them alive in flooded compartments aboard ship for a week or longer, and discharges the catch with little mortality. The major difficulty lies in avoiding loss of the tag when the crab casts its shell during molting. This problem seems to have been solved fairly well by using a tag of the type first employed by the Japanese more than 20 years ago.

This tag is essentially a piece of soft plastic tubing which is threaded through the arthral muscle at the

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junction between the carapace and abdomen. The ends are knotted and hang behind the crab with a numbered label. It has been called a "spaghetti tag" since the material resembles wet, cooked spaghetti in texture. Initially, we were seriously concerned over the effect of placing the tag in this manner. The arthral muscle is highly vascular and appears to be a major route of blood transport from the body to the heart. However, crabs which were held in live tanks following tagging showed no ill effects. Because the presence of sea water appears to be necessary to blood coagulation, the crabs were returned to the sea as quickly as possible.

We have tagged only crabs possessing firm shells and not recently molted. When newly molted and soft, the crabs are easily damaged and tagging is not deemed to be desirable because of the low recovery rates anticipated.

Returns

The degree to which we failed to obtain tags from recaptured crabs is unknown. However, it is believed that the loss from this source is relatively small. The fishery is unique in that almost all of the catch is landed at a few factory ships. Until the entry of the Soviet factory ship, generally about 80 percent of the catch was processed by the Japanese mothership *Tokei Maru*. The Japan Fishery Agency assigns a scientist to the ship who has been very conscientious in collecting recaptured tags from the fishermen. The Soviet operation has also returned numerous tags, but we are not familiar with the recovery procedure. We believe that nearly all of the tags recovered by United States fishermen were returned.

Design and Analysis of Marking Experiments

Mortality rates

To find the rates of mortality we proposed to calculate the total annual mortality rate from the rate of tag disappearance over a period of years. The part due to fishing was to be estimated by two methods: (1) recoveries after 1 year of freedom for 1956, 1957 and 1958 releases and (2) estimating numbers of crabs in the area by trawling and comparing this estimate with the catch. If we can estimate fishing mortality reasonably well, it is then convenient to estimate the mortality from causes other than fishing.

The first successful tagging took place in the summer of 1955, and tags were released each year in 1956, 1957, 1958, 1959 and 1960. Because the fishery takes only male crabs which are 13 cm or more in carapace length, only the releases of these larger male crabs are discussed. Actually, few crabs as small as 13 cm are retained commercially. For convenience, we have used carapace length to rec size. The irregular shape of the carapace makes wi difficult to measure with precision. The returns not complete for the larger more recent releases the results shown below are of a tentative nature. attempt has been made to adjust for size-selec fishing, molting, changes in fishing, or a variet other factors which should be treated in a car analysis. The data presented serve to illustrate methods employed and the progress of the work.

Table 1 shows the total numbers released returned for the first three years of tagging v plastic tube tags. The returns for 1960 are not c plete. Numbers tagged in 1958, 1959 and 1960 listed in the annual reports of the International N Pacific Fisheries Commission for these years. T are not used here because they do not provid sufficiently long series for analysis.

Table 1

Recovery of male crabs over 13 cm in carapace le released in the southeastern Bering Sea

Release year	Number Released	Number recovered 1955	1956	1957	1958	1959
1955	1099	30*	48	30	16	7
1956	2545	—	42*	125	82	56
1957	5780	—	—	34*	136*	166*

* Not used in calculations.

The data in Table 1 were used to calculate surv rates. Following Jackson's method (Ricker, 1958) mean annual survival from the 1955 tagging 0.56 and from the 1956 tagging it was 0.64. comparison with an unweighted estimate, the covery data were converted to logarithms wh transformed the series to good approximation straight lines with slopes corresponding to survival for 1955 and 0.60 for 1956. The 1957 tagg was not used because of the short series and anomaly between the 1958 and 1959 recoveries. low recovery in 1958 is believed to be due to availability caused by the distribution of taggin 1957.

Now let us consider means of estimating an fishing mortality. We obtained an approximatio fishing mortality by examining tags recovered a one year of freedom. This was compared with independent estimate derived from the numbe crabs calculated to be on the fishing grounds and catch reported by the fishing companies. Thus, have two separate estimates of fishing mortality.

The first method of estimating fishing mortalit by tagging. Before using the returns to derive estimate, it is necessary to be assured that the are well mixed through the stock. Because tag

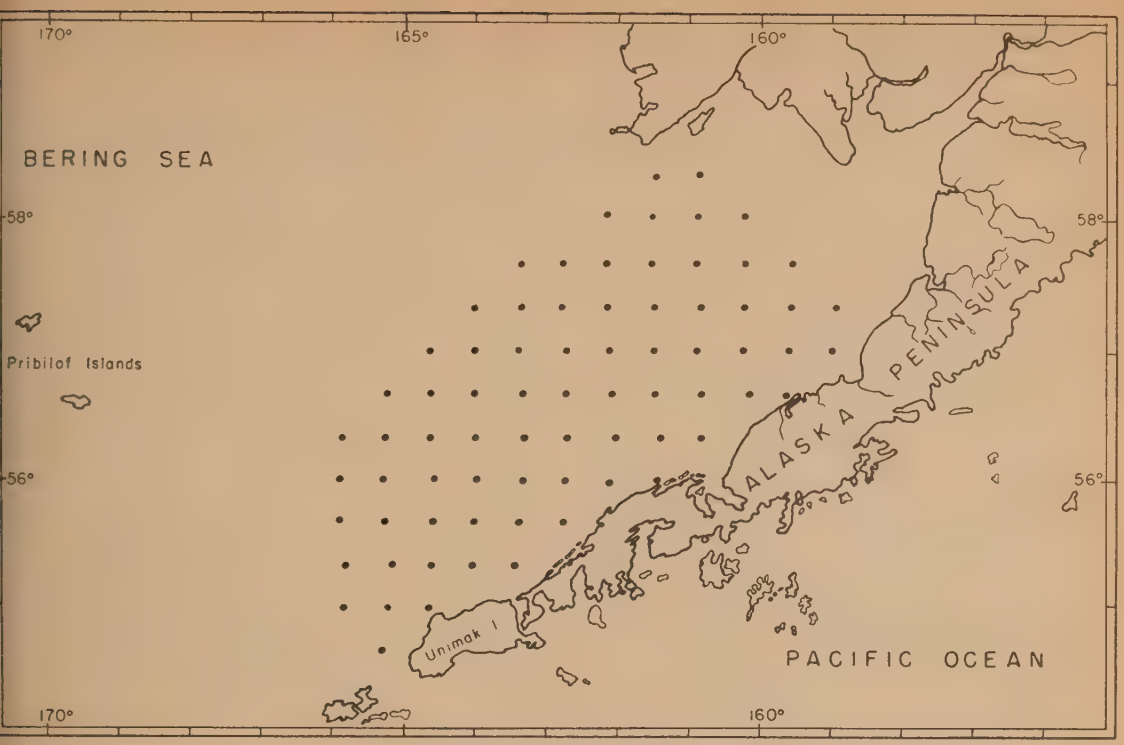

Figure 1. King crab station pattern.

bs do not appear to become thoroughly distributed hin a year after tagging, all of the releases cannot used. Two patterns of release were employed. In first, a pattern of stations 20 miles apart were ed. All of the crabs caught were tagged and ased where caught. An illustration of this pattern given in Fig. 1. Following this, mass tagging was ne where crabs were most abundant. The mass gings account for most of the crabs released. These re not distributed through the stock. However, crabs released on the station plan were systematical- distributed throughout the area in which crabs are nd. Therefore we reason that the distribution of se tagged on station should be approximately the ne as that of the stock as a whole. From the tribution of the fishery on different grounds this ms to be generally true. If it is true, it immediately omplishes good mixing of tags through the stock.

In Table 2, only station releases were used, and y those recoveries made in the first spring and mmer fishery following the year of tagging were nsidered. As mentioned earlier, the fishing was ne almost entirely during the spring and summer nths. The releases have been adjusted for recoveries hin the year of tagging. The table shows that for 56 and 1958 about 4 percent of the tags were recovered by the fishery, but for 1957 only about 1 percent. Again, the 1957 recoveries appeared to reflect a lower availability. For all three years we would expect that loss of tags, mortality of tagged crabs, and similar factors would cause these data to indicate a fishing rate lower than actually occurred.

Table 2

Recoveries in following year of crabs tagged on station

Year of tagging	Male crabs released on station	Recoveries in following summer	Percent recovered
1956	750	28	3.7
1957	348	3	0.9
1958	2617	96	3.7

The second method used to estimate fishing mortality was by comparing the numbers of crabs on the grounds with the catch in 1957, 1958 and 1959. Total numbers of male crabs of commercial size were calculated from otter trawling catches. The area covered by the trawl was used with the numbers caught to compute the average density per unit area. This was then expanded to the total area covered. The results are shown in Table 3. These estimates reflect the entry of the first large mode mentioned in

the discussion of growth. The catch of crabs by the fisheries in these years may be found in Table 4.

Table 3
Estimated number of male crabs (over 13 cm) in southeastern Bering Sea

Year	Number
1957	14,435,000
1958	20,563,000
1959	25,145,000

Table 4
King crab catch in eastern Bering Sea, 1953—1959, in thousands of crabs*

Year	Japan	U. S.	Total
1953	1276	361	1637
1954	1061	328	1389
1955	1129	313	1442
1956	1079	294	1373
1957	1171	107	1278
1958	1130	1	1131
1959	1292	—	1292**

* Source: International North Pacific Fisheries Commission Statistical Yearbooks for 1958 and 1959.

** Does not include catch by U.S.S.R. or incidental catch in bottom fish fishery.

Tables 3 and 4 provide the data to estimate directly the annual fishing mortality. For 1957 it was 0.089, for 1958, 0.055, and for 1959, 0.051.

The confidence intervals for the population estimates are quite broad, but interestingly enough, the mortality estimates for the three years are all between 5 and 10 percent. Moreover, they are probably high, since in calculating the density of crabs we assumed that all of the crabs which were between the otter boards were caught, and that our station pattern covered the entire area of the stocks. These assumptions are not entirely fulfilled. When the results of this method are compared with those from tagging, it appears that the fishing rate was less than 10 percent, and perhaps as low as 5 percent.

If for each year we use a mean of Jackson's and the line slope method of estimating annual survival (for the 1955 tagging 0.54 and 0.62 for the 1956 tagging), we then have total annual mortality rates of 0.46 and 0.38. When these are used with an annual fishing rate of 0.05, maximal annual natural mortality rates of 0.43 and 0.35 are derived for the 1955 and 1956 taggings respectively. If the higher estimate of 0.10 is used for the fishing mortality factor, the estimates of natural mortality become 0.40 and 0.31, which are similar to the rates derived using 0.05 for fishing. The estimate of natural mortality is not greatly changed whether the upper or lower estimate of fishing is used.

Mixing

Tagging showed no interchange between the st south of the Alaska Peninsula and those of the Be Sea. Within the range of the species in the so eastern Bering Sea, there appears to be but one st Consideration of hydrography, distribution and f ing studies leads us to believe that there is only major breeding group; it is almost continuous al the north side of the Peninsula. Release of larvae mating take place here. The fishery concentrates these mating adults, for the most dense aggregati of prime male crabs are found here. However group of crabs tagged at a single location mi never become distributed randomly through stock. In Table 1 the tags released in 1957 w evidently not fully available to the fishery before 19 or perhaps later. The stock is highly segregated sex, size and condition. The large hard-shelled ma the adult females and the very small of both se tend to be concentrated inshore from the n breeding crabs which include the large molting ma A large prime crab tagged on the breeding grou would probably never return to the molting c centrations found northwest of the Alaska Peninsu because the molting frequency of the larger crabs low.

Growth

In some respects the growth studies of king c (and crustaceans generally) are complicated by lack of permanent annular marks on the animal, a the irregular nature of the growth. Carapace s remains constant for long intervals and growth occ suddenly. The intervals between ecdyses vary w size, sex and age. A detailed study has been made the Bering Sea king crab (D. D. Weber and Miyahara, 1959). In this study the mean growth r was derived by using the amount of growth per m as shown by tagged crabs, combined with observati of molting proportion.

Molting of the larger male crabs takes place in spring months and appears to be limited to no m than a single molt per year. In order to establish frequency of molting it is necessary to distingu between shells that are perhaps 3 months old a those that are 15 months old or older. The shells of recently molted crabs can be generally recogni as they are cleaner and show less scratching a erosion. While the decisions are subjective, they in good agreement with data from recovered tagg crabs for which it is possible to determine whether not they molted while free. This method does insure that a larger crab would not molt later in year, or molt more than once annually as the sm crabs do. However, for large crabs it seems to unimportant because they are seldom observed

oft-shelled crabs or with bright new shells between iidsummer and midwinter.

Sampling (at the stations described above under iortality studies) was employed to determine the roportion molting for each year.

The results of this sampling showed that almost ll of the crabs less than 11 cm had molted within ie year of sampling. The proportion molting dropped radually at first with increasing size, then more and iore rapidly, until fewer than 10 percent of the rabs over 17 cm were found to be molting each year.

Mean growth in carapace length during one molt as approximately 16 mm and nearly stable for crabs om 11 to 16 cm in carapace length. A 16 cm crab ould molt to 17.6 cm. Few of the crabs become reater than 19 cm, so the bulk of the commercial tock is included in the size range for which increase t molting is known.

A model was constructed using tagging and molting ata to calculate the annual average size of a group of rabs initially 11 cm in length. The growth is shown n Table 5.

Table 5

alculated growth of a group of king crabs initially 11 cm in carapace length, from model studies

Year	Modal length (cm)	Mean length (cm)
N	11.0	11.0
N+1	12.6	12.5
N+2	14.2	13.9
N+3	15.8	15.0
N+4	15.8	15.8
N+5	15.8	16.4
N+6	17.4	16.8

The spread in length of the group increased with ime. It was estimated that after six years, with an verage length of 16.8 cm some individuals might be s small as 14.2 cm or larger than 20 cm.

The rate of growth was also examined by studying he size frequency of male crabs found on the fishing rounds from 1955 through 1959 (Weber and Miya- ara, 1959). The male crabs found on the fishing rounds were generally larger than 5 cm and smaller han 20 cm in carapace length. We were fortunate n 1955 when a distinct mode appeared at about 8 cm vhich we could follow in successive years. It was still vident in 1960. In 1957 when this mode had reached bout 11 cm, another group, less strong but still quite dentifiable, appeared near 8 cm. By 1959 the first node mentioned was near 14.5 cm. The average rogression of these modes through 1959 was ap- roximately 15 mm per year.

This compares quite closely with the modal growth hown in Table 5. The results of the study summarized n Table 5 indicate, however, that the growth of an ge-group as a whole is somewhat less than that found by following unique modes in their progress through the population. This difference arises because in any given year all male crabs do not molt. Those which fail to molt tend to skew the mode to the left and then mean length becomes smaller than the modal length.

Summary

The purpose of this paper is to consider the design and analysis of tagging experiments with the southeastern Bering Sea king crab. Migration, growth and mortality rates are of primary interest. These are discussed in a preliminary manner. Although a completed manuscript on growth is in press, the work on migration and mixing has not reached the same stage and serious analysis of mortality rate data has yet to be undertaken. The time series of tag returns has been too short to permit careful analysis. For this reason the results given here are tentative trial estimates, and have not been adjusted for the high degree of size selectivity by the fishery, changes in fishing intensity, differential availability because of variation in molting frequency by size, and similar factors. A study of these factors is being made. The material that has been presented may be summarized as follows:

1. The use of growth data from tagged crabs combined with molting proportions appears to give reliable results. The average growth in carapace length by crabs of 11 cm is 15, 14, 11,8, 6 and 4 mm in succeeding years. This does not conflict with the results of size frequency studies.
2. Tagging shows that the southeastern Bering Sea has but one stock of king crabs, which does not mix with the crabs south of the Alaska Peninsula.
3. The tagging experiments promise to yield series of data which are suitable for reasonably accurate calculation of mortality rates. The estimates suggest that the annual fishing rate has been between 5 and 10 percent and that the annual natural mortality on this basis is between 31 and 43 percent.

References

International North Pacific Fisheries Commission 1958—1961 Annual report for the year 1957, 1958, 1959, 1960.

International North Pacific Fisheries Commission. 1959—1960. Statistical yearbook 1958, 1959.

RICKER, W. E. 1958. Handbook of computations for biological statistics of fish populations. Fish Res. Bd. Canada, Bull. 119, 300 p.

WALLACE, M. MARVIN, CAMILE J. PERTUIT and ARTHUR R. HVATUM. 1949. Contribution to the biology of the king crab (*Paralithodes camtschatica Tilesius*). Fish. Leafl. 340. Wash. 50 p.

WEBER, DOUGLAS D. and TAKASHI MIYAHARA. 1962. Growth of the adult male king crab *Paralithodes camtschatica* (Tilesius). *Fish. Bull. U.S.*, 62 (200).

Schmidt & Klaunig, Kiel

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Shells and their neighbors

No. 16 APRIL 1963 45c

Some Shell MALFORMATIONS

by W. J. Clench and A. S. Merrill
Harvard College

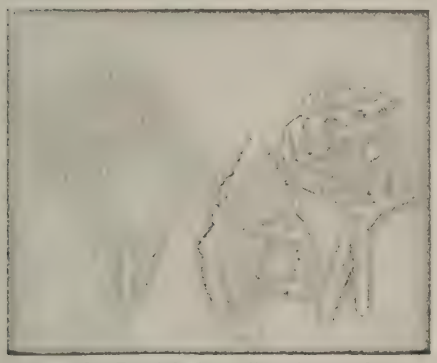

Fig. 1. **Fasciolaria tulipa** Linne from Fort Myers Beach, Florida (about ⅔ X. Fig. 2. **Distorsio clathrata** Lamarck from the Campeche Bank, Yucatan (about natural size). Fig. 3. **Murex (Haustellum) haustellum** Linne from the Indo-Pacific (about natural size).

We have been asked on frequent occasions to explain what causes certain shell malformations. Sometimes this is relatively simple to do, as the malformation may be due only to a minor break in the shell margin; other times, malformations may be due to causes not so easily understood. For this reason one can only deduce what may have happened. We are not here concerned with abnormalities of a genetic origin, but only with those which suffered some mechanical action. The immediate cause in any particular case is usually unknown, as the malformation is the result of survival and growth after the accident occurred The three unusual specimens figured will serve to illustrate three different types of accidents which are here considered.

The injury to the mantle causes the greatest distortion in the later growth of the shell, as can be seen in Fig. 1 of *Fasciolaria tulipa* Linné. In this case the animal was injured after the completion of the fifth whorl. When growth resumed, the animal was unable to produce the normal pattern of shell structure. The resulting damage to the mantle must have been such that uniform deposition of shell material was impossible.

A frequent type of malformation is a break in the shell brought about by such action as being tossed about during storms, attacked unsuccessfully by predators, or being damaged by fishing gear. The shell in Fig. 2, *Distorsio clathrata* Lamarck, was probably damaged by the action of a shrimp trawl. A hole was broken in the body whorl and later was subsequently captured after it had started an unusual type of repair. Rather than just repair the hole proper, the animal built a reflected lip, complete with crenulations on the inner side of the hole, which certainly cramped the animal in its reduced quarters.

There are many other factors which may cause malformation, such as the case in Fig. 3 of *Murex haustellum* Linne, where two siphonal canals were developed. In this instance we can detect no mechanical break in the shell. The inner area of the first siphonal canal must have become clogged at the time the animal was quiescent, so that when growth continued a second siphonal canal had to be constructed.

We wish to thank Mrs. H. Taylor Raines of Fort Myers Beach, Florida, for the loan of the disfigured speciments of *Fasciolaria* and *Distorsio* from her collection. The *Murex* is in the collection of the Museum of Comparative Zoology, Harvard University.

BREVIORA

Museum of Comparative Zoology

CAMBRIDGE, MASS. DECEMBER 31, 1963 NUMBER 196

A NEW GENUS AND SPECIES OF BATHYPELAGIC OPHIDIOID FISH FROM THE WESTERN NORTH ATLANTIC

BY DANIEL M. COHEN

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Washington, D. C.

Through the kindness of Dr. Richard H. Backus of the Woods Hole Oceanographic Institution and Dr. Giles W. Mead of the Museum of Comparative Zoology I have had the opportunity to study the three fishes reported upon below. Although they were taken off the southern edge of Georges Bank, hardly a zoologically unknown area, they represent the first of their kind ever captured. And, indeed, they are so different from any other known ophidioid that still another name must needs be added to the already lengthy roster of genera in this group.

THALASSOBATHIA gen. nov.

Diagnosis. Chin barbel absent. Vertical fins continuous; ventral fins each with two rays, originating close to the level of the posterior margin of the preopercle and a short distance behind the symphysis of the cleithra; the ventral fins covered with thick skin, short, extending only to the level of the origin of the pectoral fin; pectoral fin rounded, without separate elongated rays. Branchiostegal membranes separate; gill rakers reduced in number and size; branchiostegal rays seven. Preopercular spine present beneath skin. Anterior nostril lacking a tube, placed high on snout. Teeth present on premaxillary, vomer, palatine and dentary, lacking on basibranchials. Maxillary not expanded posteriorly, not sheathed. Premaxillary not protractile, bound to the snout anteriorly by a broad frenum. Head compressed, its height greater than its width. Eyes well developed. Body compressed, relatively short and stubby. Two lateral lines.

Peritoneum dark. Swimbladder reduced, its cavity completely occluded; bladder not bound to vertebrae. Neural spines on abdominal centra not depressed; their tips not truncate.

Type species. Thalassobathia pelagica sp. nov.

The name *Thalassobathia* is derived from the Greek θαλασσα, the sea; βαθυς, deep. The gender is feminine.

Relationships. The main problem encountered in establishing this genus has been to determine its relationships rather than to distinguish it from any presently known genera. The curiously reduced ventral fins and the general shape and consistency of the body might suggest relationship with the liparid fishes; however, there is not the slightest trace of either a suborbital stay or a sucking disc. In addition, the branchiostegal membranes are separate from each other and from the isthmus, and the gill opening extends far up on the side of the body in typical ophidioid fashion. The last character also separates *Thalassobathia* from the Zoarcidae (not including *Lycodapus*). The non-protractile premaxillaries and attached broad frenum suggest the condition of the upper jaw found in salariine blennnies; however, very different dentition, branchiostegal membranes, ventral fins, caudal fin connections and other characters separate *Thalassobathia* from the Salariinae. In addition, the absence of a one-to-one correspondence between dorsal and anal fin rays and vertebral centra separates *Thalassobathia* from any of the blennioids.

Among the ophidioids the closest known relatives of *Thalassobathia* appear to be the *Bythites — Oligopus — Cataetyx* group of genera recently discussed by Cohen (in press). Some reasons for deriving *Thalassobathia* from this group are the similarly compressed and foreshortened body, the typical bythitine dentition, and especially the double lateral line system, which greatly resembles that found in some of the species of *Oligopus* (Cohen, in press).

Although at first glance *Thalassobathia* does not appear to be a bathypelagic fish, closer examination reveals that many of its characteristics are adaptations to a midwater life. The skeleton is so poorly ossified that X-ray photographs are very indistinct. Scales are completely lacking. The swimbladder is a small, tissue-filled organ similar to those which have been found in many other species of bathypelagic fishes. The above characters and their significance in floating fishes have been treated by Denton and Marshall (1958) and Marshall (1960). Other structures which may help to keep *Thalassobathia* aloft are its subdermal fatty

layer and enlarged liver. Among the most characteristic features of ophidioid fishes are the naked ventral fin rays which probably serve as tactile organs in benthic species (Herald, 1953, and serve as tactile organs in benthic species (Herald, 1953 and Briggs and Caldwell, 1955, have confirmed this for two species of benthic Ophidiidae). These structures would of course be useless in midwater, and *Thalassobathia* has reduced ventral fin rays which are covered with thick skin.

Because of its midwater habitat, *Thalassobathia* should also be compared with the ophidioid subfamily Aphyoninae (Nybelin, 1957) which comprises a small group of bathypelagic species. Aphyonines are small, pale fishes with thin, scaleless skin, weak musculature, reduced ossification and no swimbladders. Although they are livebearing, they have a copulatory apparatus which is very different from that found in benthic livebearing ophidioids. They also lack well developed eyes and lateralis systems. I believe that neoteny has played an important part in the evolution of the aphyonines. *Thalassobathia,* with its large eyes, well developed lateralis system and bythitine dentition, seems, on the other hand, to be one more offshoot of the highly adaptive *Bythites* group of genera, and although it shares a common environment with the Aphyoninae, the two are not at all closely related.

Specimens examined in preparing the foregoing section are listed in Cohen (in press). In addition I have examined the aphyonine material described by Nybelin (1957), specimens of *Aphyonus* in the Museum of Comparative Zoology and in the British Museum (Natural History), and specimens of *Barathronus* in the U. S. National Museum and the Chicago Natural History Museum. I thank the fish curators in Cambridge, Chicago, Göteborg, London and Washington for their kindness.

Thalassobathia pelagica sp. nov.

Figures 1, 2

Holotype. MCZ 42161, 221 mm standard length, collected by Richard H. Backus on board the "Capt. Bill III," haul RHB 913; October 13, 1962; 39° 26′ N., 71° 00′ W. to 39° 32′ N., 71° 00′ W.; depth to gear 390 fms. (approx. 713 m), depth to bottom 1400-1350 fms. (approx. 2561-2469 m); time 1020 to 1505 hrs. EDT; 64 foot open midwater trawl.

Paratypes. MCZ 42162 (2); data as for the holotype.

Description. Body compressed and foreshortened, greatest depth between three and four in total length. Head relatively

FIG. 1. *Thalassobathia pelagica*, holotype, 221 mm standard length. Drawn by Mildred H. Carrington.

short, between five and six in total length. Snout rounded, mouth slightly inferior. Interorbital area flat or slightly convex. Outlines of head converging anteriorly when viewed from above. Eye prominent, horizontal diameter of cornea about three and one-half in head. Posterior nostril an elongate slit immediately in front of ventral half of eye, anterior nostril small and round, closer to tip of snout than to orbit. Body quite flexible due to weak ossification, feeling much the same as icosteid fishes.

All fins covered with thick skin. The dorsal fin appears to originate a short distance behind the level of the posterior margin of the opercle; it is preceded by rayless pterygiophores and pterygiophores bearing very reduced rays. The exact number of these elements is in doubt as their weak ossification makes them difficult to count on an X-ray photograph. Pectoral fins inserted vertically, broadly rounded; in the holotype and smallest paratype the pectoral fin extends about two-thirds of the way from its origin to the vent, in the other paratype the pectoral fin extends only about one-half of the pectoral origin to vent distance. The ventral fins much reduced and covered with thick black skin (Fig. 2C), the longer, inner ray extending only slightly beyond the level of the base of the pectoral fin. One pectoral fin was cleared and stained to verify the number of rays.

Teeth short, needle-like, extending on the dentary in a single line from the angle of the gape to the symphysis, where a broader patch of teeth is present; premaxillary teeth arranged similarly to those on the dentary; vomerine teeth in a roughly circular patch; palatine teeth in an elongate patch, about three or four times longer than wide. Suprabranchial tooth patches present; however, I have been unable to find any basi-branchial teeth. Tongue massive, lacking teeth and lacking an anterior prow-like extension. The first gill arch with rakers reduced to a few fleshy flaps and protuberances laterally (Fig. 2A), medially (Fig. 2B) with seven or eight small rakers. A prominent pseudobranch located lateral to the upper arm of the first arch. Gill filaments of moderate length, about equal to diameter of lens.

Color brown-grey over the body, the grey due mainly to a mucous coat; the fins and head darker.

Prominent pores on the head. The lateral canal with a single pore near the upper angle of the opercle; supraorbital canal with two or three pores, one above the upper nostril, another below and slightly ahead of the upper nostril, a median pore in the interorbital region of the largest paratype; infraorbital canal

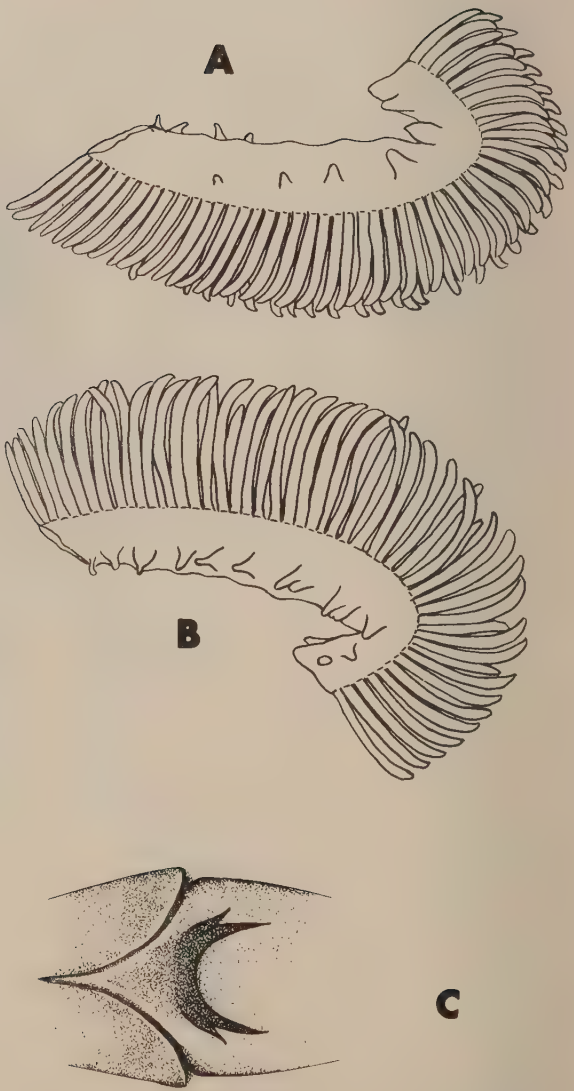

FIG. 2. *Thalassobathia pelagica.* A, First gill arch from left side of smallest paratype, lateral view. B, First gill arch from left side of smallest paratype, medial view. C, Ventral fins of largest paratype. Drawn by Mildred H. Carrington.

with nine pores, the anteriormost below the anterior nostril and immediately behind one of the supraorbital pores, six in an irregular row in the loose skin above the upper jaw, and two behind the eye; preoperculo-mandibular canal with five or six pores located along the ramus of the lower jaw; in the smallest paratype the pair of pores located closest to the midline of the lower jaw have joined to form a single pore.

Lateral line with an upper and lower section, the upper line originating above the opercle and arching upward and back to the level of the origin of the dorsal fin, where it extends posteriorly about midway between the dorsal profile and the midline; the dorsal line disappears at about two-thirds of the distance between the posterior margin of the opercle and the base of the tail; the ventral line originates slightly behind the level of the vent and extends posteriorly to the tail in the midline of the body. Each of the two lateral lines along the body is marked by about 30, small, dark, papillae; similar structures are sparsely distributed over the body and head.

Each specimen has a broad, fleshy hood over the genital area. The largest paratype has a pair of large ovaries which contain small eggs at the bases of numerous villi. The smallest paratype contains small paired ovaries with developing eggs.

The swimbladder of the smallest paratype is a white, bean-shaped organ about 14 mm long. The lumen appears to be completely occluded by white tissue.[1]

The liver is prominent in both paratypes, and the thick skin has a subdermal fatty layer.

The brain case is cartilaginous. The olfactory nerves extend anteriorly in the orbit and are separated from each other by the cartilaginous interorbital.

All three specimens bear numerous round marks left by squid tentacles. The smallest paratype has the top of its head bitten off.

LITERATURE CITED

Briggs, John C. and David K. Caldwell
1955. The characteristics and distribution of the spotted cusk eel *Otophidium omostigmum* (Jordan and Gilbert). Quart. Journ. Florida Acad. Sci., **18**(4): 285-291.

[1] I am indebted to N. B. Marshall for his kindness in examining the swimbladder.

Cohen, Daniel M.
(in press). A review of the ophidioid fish genus *Oligopus* with the description of a new species from West Africa. Proc. U. S. Nat. Mus.
Denton, E. J. and N. B. Marshall
1958. The buoyancy of bathypelagic fishes without a gas-filled swimbladder. Journ. Mar. Biol. Assoc. U. K., **37**: 753-767.
Herald, Earl S.
1953. Spotted cusk-eel, the strange fish that stands on its tail. California Fish and Game, **39**(3): 381-384.
Marshall, N. B.
1960. Swimbladder structure of deep-sea fishes in relation to their systematics and biology. Discovery Repts., **31**: 1-122.
Nybelin, Orvar
1957. Deep-sea bottom fishes. Repts. Swedish Deep-Sea Expedition 2, zoology (20): 250-345, pls. 1-7.

Table 1

Counts and measurements in mm of *Thalassobathia pelagica*

	Holotype	Paratype	Paratype
Dorsal rays	79	72	74
Anal rays	65	58	61
Pectoral rays	23	24	27
Vertebrae[1]	49	48	48
Caudal rays	10	10	10
Standard length	221	173	200
Head length	44.0	13.5	42.0
Snout	10.0	—	7.4
Orbit	11.9	—	11.0
Interorbital	16.0	—	13.3
Upper jaw length	30.0	21.8	22.2
Preanal	87.9	71.0	87.2
Greatest body depth	59.4	47.2	64.0
Body depth at vent	54.1	45.4	50.0
Pectoral fin length	28.2	23.4	25.4

[1] Not including hypural.

THE PUBLICATION DATES OF GOODE AND BEAN'S *OCEANIC ICHTHYOLOGY*

BY

DANIEL M. COHEN

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THE PUBLICATION DATES OF GOODE AND BEAN'S *OCEANIC ICHTHYOLOGY*

By Daniel M. Cohen*

The latter fourth of the nineteenth century was the birth time of comprehensive studies on fishes from the continental slopes, the abyss, and the bathypelagic realm. Günther's report on the *Challenger* collections was a mighty foundation, to which was added the report by Vaillant on fishes collected by the *Travailleur* and the *Talisman*, a series of papers by Alcock on Indian Ocean deep-sea fishes taken by the *Investigator*, reports by Collett on fishes taken in the North Atlantic by *L'Hirondelle* and Scandinavian expeditions, and the studies of Lütken and Jensen on fishes collected by the *Ingolf*.

During this early period the vessels *Blake*, *Albatross*, and *Fish Hawk* worked in deep waters of the western North Atlantic. Their collections of fishes were studied chiefly by the American ichthyologists George Brown Goode and Tarleton H. Bean. Although these authors published a number of brief preliminary papers, their *magnum opus* was a quarto text and atlas of figures entitled *Oceanic Ichthyology*. The purpose of this work was twofold: on one hand, to simply describe the deep water fauna of the western North Atlantic, and on the other, to integrate it with the deep-sea fish fauna of the world, as then understood. To this latter end, *Oceanic Ichthyology* is a study of all fishes known to the authors, which lived beyond a depth of 500 feet. The influence and importance of this book was considerable, for it represented not only description, but also a great synthetic effort (due in part to the zoologist Theodore Gill, who provided some of the ordinal, family, and generic diagnoses).

In their introduction, the authors were able to predict the fate of their work, based on the difficulties which they encountered in its production. Limited and selective sampling provided them small collections, many in poor condition, so that today, when larger series and broader geographical coverage are becoming more common for species of oceanic fishes, the major importance of *Oceanic Ichthyology* is that it contains the original descriptions of some 49 nominal genera and 147 nominal species. As such the book is an essential reference work for the zoologist who studies oceanic fishes.

Unknown to many is the fact that *Oceanic Ichthyology* was issued as part of three different series. The dates 1895 and 1896 have both been widely used in citations and question has arisen concerning the authorship and priority of some of the Goode and Bean names. Presented below are citations of the three issues taken from the volumes.

> Oceanic ichthyology, a treatise on the deep-sea and pelagic fishes of the world, based chiefly upon the collections made by the steamers Blake, Albatross and Fish Hawk in the Northwestern Atlantic, with an atlas containing 417 figures. Smithsonian Contributions to Knowledge, vol. 30, No. 981. Published by the Smithsonian Institution, City of Washington.

The first page, dated 1895, is the title page of the series. It is followed by an "Advertisement" on pages iii–vii, which discusses the organization of the Smithsonian Institution. Page viii is a list of "Officers of the Smithsonian

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Institution ". Page ix lists " Members Ex Officio of the Smithsonian Institution ". Page x lists " Regents ". Following is the title page of the book cited above and dated 1895. The verso of the title is blank. Following this is an unnumbered page (recto) listing the " Commission to Whom This Memoir Has Been Referred ". Then an " Advertisement ", dated July 1895 in p. [i]. An " Introduction " by the authors on pages iii–viii is dated 1 April 1895. Beginning with the " Introduction ", all three editions are identical.

> Oceanic ichthyology, a treatise on the deep-sea and pelagic fishes of the world, based chiefly upon the collections made by the steamers Blake, Albatross, and Fish Hawk in the Northwestern Atlantic, with an atlas, containing 417 figures. Smithsonian Institution. United States National Museum. Special Bulletin. Government Printing Office, Washington.

The first page is the title page cited above and dated 1895. Following on page ii is an " Advertisement ", dated 3 June 1895. Oceanic Ichthyology is here cited as Special Bulletin No. 2. On page iii the " Introduction " mentioned under the previous issue commences.

> Reports on the results of the dredging, under the supervision of Alexander Agassiz, in the Gulf of Mexico (1877–78), in the Caribbean Sea (1878–79), and along the Atlantic coast of the United States (1880), by the U.S. Coast Survey steamer " Blake," Lieut.-Com. C. D. Sigsbee, U.S.N., and Com. J. R. Bartlett, U.S.N., commanding. Published by permission of Carlile P. Patterson and W. W. Duffield, superintendents of the U.S. Coast and Geodetic Survey. XXXVI. Oceanic ichthyology, a treatise on the deep-sea and pelagic fishes of the world, based chiefly upon the collections made by the steamers " Blake," " Albatross," and " Fishhawk " in the Northwestern Atlantic, with an atlas containing 417 figures. Published in connection with the National Museum and the Smithsonian Institution. Memoirs of the Museum of Comparative Zoology at Harvard College, Vol. XXII. Printed for the Museum, University Press: John Wilson and Son, Cambridge, U.S.A.

The first page, giving the name of the series, is dated 1896. It is backed by a page bearing the name of the press. Following is a page headed " Contents " bearing the above citation. It is backed by a blank page, which is followed by the title page, dated September 1896. The title page backing is also blank and is followed by the " Introduction ", identical with the one in the two subsequent editions.

The reader may well ask why three editions, identical in all but the pre-introduction pages, were issued. The following quotation from the second " Advertisement " of the Smithsonian Contribution to Knowledge edition sheds some light. " The following memoir, by Doctors G. Brown Goode and Tarleton H. Bean, having been published at the joint expense of the Smithsonian fund and of the printing appropriation of the United States National Museum, two separate editions are issued, one forming a portion of the series of Smithsonian Contributions to Knowledge, and the other appearing as a special bulletin of the United States National Museum."

As for the edition published in the Memoirs of the Harvard Museum, I quote part of a letter, dated 3 December 1889, from Alexander Agassiz to G. Brown Goode.

Very glad to hear from yours of the 28th Nov. of the good progress of the "Deep Sea Fishes of The Atlantic Basin" I suppose it will make a full Vol. of our Bulletin? and I should like to have an edition for the Museum of say 500 [350 crossed out and 500 added in pencil, D.M.C.] copies adding to the general title p. which you have for the N.M. Bull. XXXVIII our regular title p. and a title showing that the material is U.S. Fish Comm. and "*Blake*" but probably the latter will be included in your title and shall need only our regular title p. which can be sent in from here to your binder and add to our 500 copies. [350 crossed out and 500 added in pencil, D.M.C.]

Records in the U.S. Government Printing Office show that a single printing, apparently of all three editions, was made some time during 1895. The exact date of publication, however, of each of the three editions is a point of some confusion.

The following letter makes it apparent that none of the three editions had appeared by 20 July 1896.

July 20, 1896

Professor Alexander Agassiz:
Museum of Comparative Zoology,
Cambridge, Massachusetts.

My dear Mr. Agassiz:

I have your letter of the 18th, and have directed that the 300 copies (text and plates) of "Oceanic Ichthyology" be packed at once. As soon as this is done, the boxes will be forwarded by freight.

You asked at the time that the extras were ordered from the Printing Office, that the cover and title-page be omitted. I notice that the copies as received are accompanied by the title-page, but this can be easily separated and cast aside.

I will send you the bill for the paper and presswork as soon as it is received from the Public Printer. The packing will be done in the Museum shops, and there will be no charge on this account.

The copies of text of the Smithsonian edition have mostly been received, but the plates have not yet been delivered. None of the Museum edition has been received. When they come, I shall be pleased to send you one of the first copies of each—that is, in the form of the "Contributions to Knowledge" and the "Special Bulletin".

Trusting that the separates will reach you safely, and that you may be pleased with the work, I am

With kind regards,
Yours very truly,
G. Brown Goode (signed)
Assistant Secretary,
Smithsonian Institution,
in charge of the U.S. National Museum

By 9 August 1896 at least one copy had been distributed. I quote from a letter of this date from Dr. Goode to Dr. Albert Günther.

I am sending you today, through Wesley, the *first copy* of our " Oceanic Ichthyology ". I only hope that you will not find many things in it to displease you.

A letter dated 9 September from F. W. True of the U.S. National Museum, to Professor Agassiz states that the Smithsonian Edition was not out until September, so the copy mailed to Dr. Günther must have been the U.S. National Museum edition. Part of Dr. True's letter is quoted below.

> . . . I would say that the Smithsonian volume, containing the plates accompanying Oceanic Ichthyology, has only very recently been received. A copy was mailed to you on Sept. 5.

Although Dr. Günther was sent the first copy of what was probably the U.S. National Museum edition on 9 August, it may well have been a prepublication copy, for the Smithsonian publication files give 16 August 1896 as the earliest distribution date and 27 August 1896 as the publication date of U.S. National Museum Special Bulletin No. 2. On the other hand, a letter dated 14 August 1896, from Dr. Goode to Mr. Penning of Cleveland, Ohio, stated that the U.S. National Museum edition had already been issued.

There is no doubt then that all three of the editions came out in 1896, rather than 1895, as two of them are marked. Professor Agassiz remarked on this in a letter, dated 16 September 1896, to Dr. True, part of which is quoted below.

> The 14 boxes came safely to hand and I hope to have our edition out in a few weeks. It is a pity the date 1895 is so far out of the way of the issue in fact. July/96?

The exact date of publication of any of the three editions remains a subject for conjecture; however, it seems fairly certain that the U.S. National Museum Special Bulletin was the first edition published and that it appeared at some time during August of 1896.

Dr. Denys Tucker has suggested that attention should be called to the fact that some of the families, genera, and species described as new in *Oceanic Ichthyology* were in fact originally published by Goode and Bean at an earlier date. The names listed below first appeared in a series of three papers which were issued on 26 January 1895, as part of volume 17 of the *Proceedings of the U.S. National Museum*. Page references are for Volume 17.

Cetomimidae	new family	page 451
Cetomimus	new genus	page 452
C. gillii	new species	page 452
C. storeri	new species	page 453
Rondeletiidae	new family	page 454
Rondeletia	new genus	page 454
R. bicolor	new species	page 454
Gigliolia	new genus	page 464
G. moseleyi	new species	page 465
Macdonaldia	new genus	page 467
Lipogenyidae	new family	page 469
Lipogenys	new genus	page 469
L. gillii	new species	page 469
Harriotta	new genus	page 471
H. raleighana	new species	page 472

Acknowledgements

I thank Miss Helena Weiss, Mrs. Eileen McCarthy, and Mr. Paul Oehser of the Smithsonian Institution for their kind help in locating documents and in other ways. I also thank Mr. Joseph A. King of the U.S. Government Printing Office for his assistance. The letters quoted in this paper are in the archives of the U.S. National Museum, whose officials I thank for allowing me access.

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OMMENTS ON THE IDENTITY OF THE MEDITERRANEAN FISH *STRINSIA TINCA*

By Daniel M. Cohen,
U.S. Fish and Wildlife Service, Washington
and
Menico Torchio
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s 1810 the naturalist Rafinesque-Schmaltz gave a brief original description f *Strinsia tinca*, a Sicilian fish with connected dorsal, anal and caudal ns. Since that time the fish has been variously classified or completely nored by the many authors who have written on Mediterranean fishes. onaparte (1832) presented a description and a coloured illustration of a sh with confluent vertical fins, which he identified as *Strinsia tinca* afinesque, even though Bonaparte noted that his *Strinsia tinca* differed om the fish described by Rafinesque in its lack of a barbel on the lower w. Unfortunately there is no type of the Rafinesque species.

More recently Torchio (1960) has identified as *Strinsia tinca* a fish taken t Messina, and he has designated this specimen as a neoholotype. He marked that his fish resembled the illustration and description given by onaparte, with the exception that his fish was more stubby. Torchio lso commented on the absence of a barbel in his neoholotype.

In a subsequent paper Torchio (1961) discussed the relationships of his pecimen and concluded that it should be placed in the anacanthine mily Moridae. His figures and description stressed the resemblance of onaparte's and Torchio's *Strinsia tinca* with *Gadella maraldi*. The ajor difference, in fact, is that the latter species has a caudal fin which free from the dorsal and anal fins. Vinciguerra (1883) had earlier uggested that *Strinsia tinca* might be a mutilated specimen of some adoid species, probably *Uraleptus maraldi* (=*Gadella maraldi*).

Examination of an X-ray photograph of the neotype of *Strinsia tinca* hows conclusively that the specimen is a mutilated individual. The st vertebral centrum is broken off abruptly; there is no trace of any keletal support for the caudal fin rays; and the caudal fin rays must ertainly be regarded as regenerated elements. There seems no doubt, herefore, that Vinciguerra's hypothesis is correct. *Strinsia tinca* of onaparte and Torchio is actually *Gadella maraldi* (Risso).

If the neotype designation of *S. tinca* Rafinesque were accepted, then he genus *Strinsia* Rafinesque, 1810, would have to replace *Gadella* Lowe, 843 (type species *Gadella gracilis* Lowe, 1843; a junior subjective synonym f *Gadus maraldi* Risso, 1810).

We do not believe, however, that *Strinsia tinca* Rafinesque and *S. tinca ensu* Bonaparte and Torchio are one and the same species. Rafinesque

described *S. tinca* as having two dorsal fins, the first with 10 rays; the dorsal, anal and caudal fins continuous; a barbel under the lower jaw; and the lower jaw much shorter than the upper. It seems to us that the absence of barbels on Bonaparte's and Torchio's specimens, and the fact the lower jaw is not much shorter than the upper, removes them from consideration as being identical with the species described by Rafinesque. There is, therefore, reason to reject Torchio's (1960) neotype designation as invalid. One of the qualifying conditions for valid designation of a neotype (1961 Internat. Code Zool. Nomencl., p. 81) is the presentation of " evidence that the neotype is consistent with what is known of the original type material, from its description and from other sources. . . ." As we have shown above, there are important differences between the neotype and the original description.

The characteristics of *S. tinca* as given by Rafinesque are actually more suggestive of the family Macruridae. Of the six species of rattails which Tortonese (1958) has listed as occurring in the Mediterranean, two can be eliminated immediately. *Trachyrhynchus scabrus* was described in 1810 by Rafinesque, and *Hymenocephalus italicus* Giglioli, 1884, has a terminal mouth with subequal jaws. As for the other four species (*Macrurus sclerorhynchus* Valenciennes, 1884; *Coelorhynchus coelorhynchus* (Risso), 1810; *Chalinura mediterranea* (Giglioli), 1893; and *Macrourus aequalis* Gunther, 1878), the original description could fit any of them. *Strinsia tinca* Rafinesque, 1810, must therefore be considered a *nomen dubium.*

References

Bonaparte, C. P. 1832. *Iconographia della fauna Italica.* iii. Pesci. Roma.

Rafinesque-Schmaltz, C. S. 1810. *Indice d'ittiologia Sicilana.* Messina. 1–70, 2 pls.

Torchio, M. 1960. Ritrovamento di *Strinsia tinca* Raf. nelle acque di Messina (Pisces Gadiformes). *Atti Soc. Italiana Sci. e del Mus. Civ. Stor. Nat. Milano,* **99** (4), 430–434 pls. 24–25.

——. 1961. Attribuzione del genere *Strinsia* Raf. 1810 alla famiglia *Moridae* Svetovidov 1937 e segnalazione di *Haloporphyrus lepidion* (Risso) 1810 nelle acque messinesi (Pisces, Gadiformes). *Ibid.* **100** (4), 361–372, pl. 21.

Tortonese, E. 1958. Elenco dei Leptocardi, Ciclostomi, Pesci cartilaginei ed ossei del Mare Mediterraneo. *Ibid.* (4), 309–345.

Vinciguerra, D. 1883. Risultati Ittiologici delle crociere del " Violante." *Ann. Mus. Civ. Storia Nat. Genova.* **18,** 554–560, pl. 3.

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pp. 215–216

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COLLECTED WORKS, VOL. IV, ICHTHYOLOGY. By L. S. Berg. Acad. Sci. U.S.S.R. 746 pp., 1961. Editor-in-chief, G. U. Lindberg. Available from Four Continent Book Corp., 156 Fifth Avenue, New York 10, N. Y. $9.50 plus ten per cent handling.—The following is based partly on a review by P. G. Borisov published in *Voprosy Ikhtiologii 1962, Vol. 2, No. 1(22): 203–4*. This review was translated for me by Robert D. Jackson.

This, the fourth volume of the collected works of the academician Liva Semenovich Berg, contains a very small part of his works in the field of ichthyology. The papers on the distribution of fishes and on fossil fishes are not included here but will be published in the next volume (V). The editor divided the articles in the present volume into the following sections:

(1) Classification of fish-like vertebrates and fishes (11 papers); (2) notes on the systematics of fishes (21 papers); (3) surveys of freshwater fauna of various areas (8 papers); (4) embryology of fishes (1 paper); (5) biology of salmon (7 papers); (6) notes on the biology and distribution of fishes (13 papers); (7) results of ichthyological research (1 paper).

The first section begins with a general paper of 51 pages, "Fishes," from the "Encyclopedia Granat." This is followed by a Russian version of "A survey of the lampreys of the northern hemisphere" which was originally published in English. In two papers—"The position of the Polypteridae in the classification of fishes," and "The position of Acipenseriformes in the classification of fishes"—Berg opposes the opinion of A. N. Severtsov, who considered the Polypteridae and Acipenseriformes as ancient forms, and included the Polypteri in the Crossopterygii. Berg gives data in favor of placing the Polypteri, Acipenseriformes, and Paleonisci close together. Following this, there are two short papers on the systematics and classification of pikes (6 pp.). Perhaps the most important paper in this section is Berg's 1907 study on "The Cataphracti of Lake Baikal (Cottidae, Cottocomephoridae and Comephoridae)" (39 pp.).

The series of papers on the freshwater fishes of southern Asia is of particular interest in the second section of 21 short papers on systematic ichthyology (48 pp.).

The third section includes papers on the freshwater fishes of various areas in Eurasia. It begins with one of Berg's first papers (1898), "The fishes of the Trans-Caspian Region, collected by P. A. Varentsov." Following this, there are papers on the fishes of Korea (8 pp.); the fishes of the Sungari River at Harbin, China (12 pp.); a description of the young of several species of fishes from the basin of the Dushambink River (5 pp.); the freshwater fishes of the Gulf of Finland area with keys (32 pp.); and the fishes of the Kola Peninsula, north of the White Sea (21 pp.). This section ends with Berg's 73-page paper on "The freshwater fishes of Iran and the bordering countries" which is particularly useful for the study of the fishes of the Near East.

The fourth section, with one 39-page paper on fish embryology, describes the early stages of development in the pike (*Esox lucius*). This paper is based on Berg's graduate thesis and was first published in 1899.

Seven papers make up the fifth section on the biology of the salmons. Berg's 1935, 106-page paper, "Materials on the biology of the salmon," and his 1937, 15-page supplement, "New data on the biology of the salmon (*Salmo salar*)" contain a vast amount of valuable information on such phases of salmon biology as spawning time, geographic distribution, summer and fall races, sex ratios, eggs, age, and migrations, backed up with numerous tables. Berg was an advocate of the freshwater origin of the Salmonidae as he pointed out in "Concerning the origin of trouts and other freshwater salmon" which was first published in 1948.

The sixth section consists of 13 papers of notes on the biology and distribution of fishes (32 pp.). Three of the shortest papers are distributional notes on *Sarda sarda* and

Roccus labrax in the Black Sea. The two papers on deep sea fishes which Borisov commented very favorably on in his review are merely popular articles as is typical of papers published in *Priroda*.

The last section by Berg and Svetovidov concerns the progress in Soviet ichthyology during the 25 years from 1917 to 1942 (14 pp.). A number of Russian workers and the topics of their investigations during this period are listed under three fields of ichthyology: systematics, faunal studies and zoogeography, and ecology.

The use of the entire volume is greatly facilitated by the 61 pages of indices that follow the text. This is particularly so because the papers are not arranged chronologically and the six divisions are rather artificial. There is an index to the fishes mentioned in the papers (34 pp.), most of which are scientific names (25 pp.), and the rest common names, mostly in Russian. The geographic index (16 pp.) is mostly in Russian. There is an index to the authors mentioned in this volume (11 pp.), mostly Russians (7 pp.). The indices are followed by a table of contents listing the papers and giving the page references in the volume.

Reference to the original publication of each paper is given following the paper. One should refer to this volume with some caution to ensure that changes have not been made from the original. This is particularly true where papers have been translated. Although Berg was a Russian, many of his papers were originally published in English, German, and French, and the non-Russian ones have all been translated into Russian for this volume. In the second section, 11 of the 21 papers were originally published in English, 7 in Russian, 2 in German, and one in French. I have found a few changes, deletions, and additions in a cursory perusal of the volume. For example in Berg's "On some South China loaches," the size of the specimens in the figures was originally indicated as "×2" and "×1½" and in the reprint this has been changed to "80 mm." Also, *samka* (= female) has been added to the legend for Fig. 1 (p. 249). Originally this paper was published in Russian followed by a complete English version (as was done with Berg's 1940 "Classification of Fishes"). The English version has naturally been deleted in this all-Russian volume. But whereas the original paper was on pages 314–8 of the *Bull. Mosk Obsh. Inst. Prir. Otd.*, it is cited as page 314–6 in the reprint because the English part was omitted. This kind of problem will occur more and more often as papers are translated and reprinted. The only solution that I know of is for the editor of any translation or reprint to clearly indicate what he is doing. Along these lines, it is unfortunate that the editors of this volume have not put the original pagination in the margin to make the work more useful to the researcher who may need to consult the original paper, particularly in the case of systematic papers containing descriptions of new taxa.

Many of the papers in this volume have not been generally available to Western workers and it will certainly facilitate ichthyological research to have this collection of 62 of L. S. Berg's papers on fishes brought together in one volume. The editor of the volume, Professor G. U. Lindberg, and his assistants have performed a great deal of painstaking work in selecting, translating, and indexing these papers. Except for disagreements as to the relative value of some of the papers included compared with some that were omitted, and as to how to solve some of the problems involved in reprinting papers, their work has been highly successful. Volume IV (Ichthyology) of the collected works of L. S. Berg will be of great value to ichthyologists and fishery biologists. We await the publication of Volume V to further aid in making the papers of the great Russian ichthyologist more generally available. — Bruce B. Collette, *Bureau of Commercial Fisheries Ichthyological Laboratory, U. S. National Museum, Washington 25, D. C.*

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pp. 582–583

THE SYSTEMATIC STATUS OF THE GULF OF MEXICO BUTTERFISH, *PORONTUS BURTI* (FOWLER).—Caldwell

(1961, *Bull. So. Calif. Acad. Sci. 60[1]:19–31*) recently showed that *Peprilus burti* Fowler (1944, *Notulae Naturae no. 142*) from the Gulf of Mexico is referable to the genus *Poronotus*, and he also synonymized *burti* with the Atlantic coast butterfish, *Poronotus triacanthus* (Peck). Caldwell found that the Gulf of Mexico population was much deeper bodied that the Atlantic coast population north of Cape Hatteras in both shallow and deep water, and south of Hatteras at depths greater than 12 fathoms. However, he found a third population intermediate in body depth between the Gulf and Atlantic populations in waters of 12 fathoms or less from Cape Hatteras to Cape Canaveral (Caldwell, *op. cit. pl. 9, Table 1*). Examination of Caldwell's photograph of representatives from the three populations indicated to me that *burti* might be a valid species or subspecies. In the hope of finding an additional differentiating character, radiographs were taken of material in the collections of the U. S. National Museum, the University of Miami Marine Laboratory, and the Bureau of Commercial Fisheries Biological Laboratory, Brunswick, Georgia. The holotype of *Peprilus burti* (Acad. Nat. Sci. Phila. 55841) and the five paratypes (ANSP 55842–3, 70943–5) were also X-rayed.

All specimens had 13 precaudal vertebrae except one from the coast of North Carolina with 14 (SILVER BAY Station 1487). All but four Gulf of Mexico specimens had 17 caudal vertebrae while most from the Atlantic coast had 18 or 19 (Table 1). Comparison of Atlantic coast specimens from north of Hatteras with those from deep (13+ fm) and shallow (1–12 fm) waters south of Hatteras showed no important differences (Table 1). There is no tendency for the shallow-water population south of Cape Hatteras to be intermediate in vertebral number between the Atlantic and Gulf populations.

Only four specimens of 180 from the Atlantic Ocean and two of 96 from the Gulf of Mexico overlap in vertebral number (Table 1). The overlapping specimens are one from Alabama (USNM 159714) and one from off the Mississippi delta (USNM 187987) with 18 caudal vertebrae and four from the Atlantic with 17 caudal vertebrae. The two Gulf individuals closely resemble others from the Gulf in body depth. One from Virginia (USNM 90790) is slender bodied like most of the Atlantic population. However, the other three Atlantic specimens with 17 caudal vertebrae (one from Brunswick, Ga.; USNM 124307, Sea Is., Ga.; USNM 156113, Cape Canaveral, Fla.) are very deep bodied. This variation may be interpreted in two ways. These three fish may be Gulf of Mexico individuals that made their way into the Atlantic, or they may be unusual Atlantic specimens in both body depth and vertebral number. I favor the latter explanation because other variants were found (Table 1).

Measurements of body depth on the specimens X-rayed confirmed Caldwell's findings that the butterfish south of Cape Hatteras in depths up to 12 fathoms are intermediate between the deep-bodied Gulf of Mexico population and the slender-bodied population in deeper and more northern Atlantic waters. Caldwell noted that butterfish in the Gulf of Mexico are not found to as great a depth as they are along the Atlantic coast. I interpret the "intermediate population" as

TABLE 1. FREQUENCY DISTRIBUTION OF CAUDAL VERTEBRAL COUNTS IN *Poronotus triacanthus* AND *Poronotus burti*

	16	17	18	19	20
P. triacanthus					
Nova Scotia–Maine				8	
Massachusetts			3	12	1
Connecticut–New Jersey			3	4	
Delaware–Virginia		1	8	16	
North Carolina			6	57	
South Carolina–Georgia		2	7	16	
East Florida		1	8	24	1
P. burti					
West Florida		17			
Alabama		17	1		
Mississippi	1	15			
Louisiana	1	18	1		
Texas		19			
Campeche		6			
P. triacanthus					
Nova Scotia–Hatteras		1	15	40	1
Hatteras–Florida 13+ fm			2	23	
Hatteras–Florida 1–12 fm		2	19	73	1
P. triacanthus					
Total Atlantic coast		4	36	138	2
P. burti					
Total Gulf of Mexico	2	92	2		

individuals that are deeper bodied because of a difference in growth rate resulting from living in the warmer, more productive inshore waters.

The 98% separation in vertebral number between Gulf of Mexico and Atlantic butterfish coupled with the less distinct differences in body depth shown by Caldwell lead me to conclude that *Poronotus burti* (Fowler) must be considered a valid species. Differentiation of fishes in the Gulf of Mexico from their cognates on the Altantic coast with a hiatus in the distribution around the southern tip of Florida (see Caldwell's map, *pl. 7*) has been discussed by Ginsburg (1952, *J. Wash. Acad. Sci. 42[3]:84–101,* and earlier papers) and more recently by Miller (1959, *Tulane Stud. Zool. 7[2]:35–68*).

I wish to thank Daniel M. Cohen, J. A. F. Garrick, and Victor G. Springer for their helpful comments. The radiographs were taken by William L. Witt.—Bruce B. Collette, *Bureau of Commercial Fisheries Ichthyological Laboratory, U. S. National Museum, Washington 25, D. C.*

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THE FIRST RECORD OF THE SHORT BIGEYE, *PSEUDOPRIACANTHUS ALTUS*, FROM THE CARIBBEAN SEA.—In two recent papers, Caldwell (1962a, *U. S. Fish and Wild. Serv. Fish. Bull. No. 203* and 1962b, *Copeia [2]:417–24*) has summarized the known distribution of *Pseudopriacanthus altus* (Gill) as the Atlantic and Gulf coasts of the United States from Maine to Mississippi plus Yucatan, Bermuda, Cuba, and the Virgin Islands. All five specimens from the West Indies are from the Atlantic side of the islands. Three specimens of *P. altus* were taken on a recent cruise of the M/V OREGON at Station 3577 on 23 May 1962, in the Caribbean Sea off Nicaragua, 12°32′N, 82°25′W in 85 fathoms of water with a 40-foot shrimp trawl. The surface temperature was 27.8°C and the bottom temperature was 20°C. This constitutes a range extension of about 800 miles from the Yucatan record. The specimens (120, 90, and 86 mm standard length) are now catalogued as U. S. National Museum no. 187974. Meristically and morphometrically, they agree very closely with the description given by Caldwell. They have the black band on the end of the caudal fin typical of juveniles and subadults of this species (see Caldwell, 1962b, *op. cit. fig. 30*).——BRUCE B. COLLETTE, *Bureau of Commercial Fisheries Ichthyological Laboratory, U. S. National Museum, Washington 25, D. C.*

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The Subfamilies, Tribes, and Genera of the Percidae (Teleostei)

Bruce B. Collette

The Subfamilies, Tribes, and Genera of the Percidae (Teleostei)

Bruce B. Collette

Two phyletic lines are recognized within the Percidae: the Percinae, in which the anteriormost interhaemal bone is much larger than the posterior ones and the anal spines usually are well developed, and the Luciopercinae in which the interhaemal bones are of uniform size and the anal spines are poorly developed. Parallel evolution has produced in each subfamily small, bottom-dwelling forms with depressed or terete bodies and reduced or vestigial swimbladders. This differentiation is shown by dividing each subfamily into two tribes. Within the Percinae, the Etheostomatini (*Percina, Ammocrypta, and Etheostoma*) are interpreted as derivatives of the Percini (*Perca, Gymnocephalus* [= *Acerina*], and *Percarina*). In the Luciopercinae, the Romanichthyini (*Zingel* [= *Aspro*] and *Romanichthys*) have evolved from the Luciopercini (*Stizostedion* [including *Lucioperca*]). A table of vertebral numbers is given.

ALTHOUGH there is general agreement on the genera to be placed in the Percidae and on the species to be placed in each genus, there is no such unanimity concerning the taxa between family and genus. Most workers have divided the Percidae into two subfamilies (or families, Jordan, 1877, 1923), the Percinae with six genera (*Perca, Acerina, Percarina, Aspro, Stizostedion,* and *Lucioperca*) and the Etheostomatinae with at least three genera (*Percina, Ammocrypta,* and *Etheostoma*). Gill (1861a) erected the subfamilies Percarinae and Asperulinae for *Percarina* and *Aspro,* respectively. Others (e.g., Jordan and Evermann, 1896; Hubbs, 1926; Eddy and Surber, 1943, 1947; Hubbs and Lagler, 1947, 1958) placed *Stizostedion* and *Lucioperca* in the Luciopercinae (or Sandrinae). Dumitrescu, Bănărescu, and Stoica (1957) recently described *Romanichthys* and placed it and *Aspro* in a new subfamily, the Romanichthyinae.

From examination of radiographs, skeletons, or cleared and stained representatives of all presently recognized genera of Percidae (including all but one of the European species) I have found osteological characters that help to clarify the classification of the Percidae at the subfamily level. Additional information from preserved material of most species in the family supplements the osteological data and enables the grouping of genera into tribes. This paper is the third in a continuing series on the systematics of the Percidae (see Collette, 1962; Collette and Yerger, 1962).

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Material

Identifications were made or verified by the author. Material is from the collections of the U. S. National Museum; Academy of Natural Sciences, Philadelphia; Museum of Comparative Zoology, Harvard University; University of Michigan Museum of Zoology; Cornell University; Tulane University; and Charles University, Prague. The number of specimens examined follows each category of material.

Radiographs. *Perca flavescens,* 21; *P. fluviatilis,* 100; *P. schrenki,* 12; *Gymnocephalus acerina,* 1; *G. cernua,* 67; *G. schraetser,* 24; *Percarina demidoffi,* 3; *Percina caprodes,* 1; *P. uranidea,* 13; *Ammocrypta beani,* 14; *A. pellucida,* 12; *A. vivax,* 5; *Etheostoma chlorosomum,* 15; *E. collis collis,* 16; *E. cragini,* 14; *E. edwini,* 4; *E. euzonum,* 6; *E. fusiforme,* 20; *E. gracile,* 23; *E. grahami,* 25; *E. jessiae,* 6; *E. okaloosae,* 23; *E.*

pottsi, 4; *E. punctulatum*, 3; *E. serriferum*, 10; *Stizostedion canadense*, 15; *S. lucioperca*, 6; *S. vitreum*, 20; *S. volgense*, 5; *Zingel asper*, 9; *Z. streber*, 25; *Z. zingel*, 20; and *Romanichthys valsanicola*, 17.

Cleared and stained. *Perca fluviatilis*, 3; *Gymnocephalus cernua*, 3; *G. schraetser*, 2; *Percina peltata*, 1; *Ammocrypta asprella*, 3; *Etheostoma blennioides*, 2; *E. collis collis*, 2; *E. edwini*, 4; *E. exile*, 4; *E. flabellare*, 2; *E. fusiforme fusiforme*, 18; *E. fusiforme barratti*, 2; *E. gracile*, 8; *E. okaloosae*, 2; *E. olmstedi*, 5; *E. proeliare*, 2; *E. saludae*, 2; *E. serriferum*, 6; *E. spectabile*, 2; *E. variatum*, 3; *E. vitreum*, 1; *E. zonale*, 3; *Zingel streber*, 1; *Z. zingel*, 2; and *Romanichthys valsanicola*, 2.

Skeletons. *Perca flavescens*, 5; *Percina caprodes*, 1; *Etheostoma blennioides*, 1; *E. olmstedi*, 2; *Stizostedion canadense*, 1; and *S. vitreum*, 2.

Nomenclature

Before considering the morphological data, some clarification of the generic nomenclature is necessary. The two North American species of pikeperches (*canadense* and *vitreum*) usually have been placed in *Stizostedion* Rafinesque (1820:23) while the three European pikeperches (*lucioperca, marina, and volgensis*) have usually been placed in *Lucioperca*, a name incorrectly attributed to Cuvier (1817). As pointed out by Gill (1894:126) and others, Cuvier's use was as *"lucio perca,"* a descriptive vernacular, referring to Les Sandres (*Perca lucioperca*). The first available use of *Lucioperca* is that of Schinz (1822:475, type species *Perca lucioperca* Linnaeus by monotypy). In the same year, Fleming (1822: 394) listed *Lucioperca* (*L. vulgaris*) as a subgenus of *Perca*. Although Fleming's usage was accepted by Jordan and Evermann (1896:1020), I am forced to reject his subgenus *Lucioperca* as unavailable because there is no description and the only species name (*vulgaris*) has not been used for a pikeperch. The name *vulgaris* has been used for *Acerina cernua* (by Cuvier *in* Cuvier and Valenciennes, 1829:4) as well as for both *Aspro asper* and *A. streber* (by Cuvier *in* Cuvier and Valenciennes, 1828:188).

Gill (1903), Chevey (1925), and Cărăusu (1952) considered that the first available name was *Sander*, originating in Oken (1817). Sander is listed in the column entitled "Cuvier's System" on page 1182 (misprinted 1782) of Oken but the closes approach to it in the columns labeled "Oken' System" is on the succeeding page where under Barsche, is listed "Perca, etc." There fore, it does not seem to me that in thi case Oken was either proposing or acceptin a generic name. Oken gave no indicatio of doing more than referring to the *Règn Animal* when he used Sander, the Austria vernacular version of Les Sandres. Furthe more, Oken's system is apparently modifie from his *Lehrbuch der Naturgeschicht* (Oken, 1816) where he placed *fluviatili cernua, lucioperca, zingel*, and *aspera* all i *Perca* without mention of Sander.

Absolute junior synonyms of *Lucioperc* Schinz include: *Sandat* Cloquet, 1827; *Sa drus* Stark, 1828; and *Lucioperca* Cuvier i Cuvier and Valenciennes, 1828. *Mimoperc* Gill and Jordan *in* Jordan, 1877 (typ species *L. volgensis* by original designation) is an additional junior synonym.

I would accept *Lucioperca* Schinz as th correct name for the three European pik perches if they were deemed generically separable from their two North America relatives, but the great similarities betwee these five species have led a number o workers over the years to consider the congeneric (Gill, 1861a; Jordan, 1877; Gil 1894; Berg, 1949; etc.). At present there no good evidence for maintaining two ge era and the valid name for the genus ther fore is *Stizostedion* Rafinesque, 182 Apparently Smith and Bailey (1961:357 came to a similar conclusion because th listed both American and European speci under *Stizostedion* in the appendix to the paper. Synonyms of *Stizostedion* thus i clude *Cynoperca* Gill and Jordan *in* Jorda 1877, as well as those listed above for *Luci perca* Schinz.

The generic name *Aspro* Cuvier cann be used for the three European speci (*aspro, streber*, and *zingel*) commonly r ferred to it. It is a junior homonym *Aspro* Commerson in Lacépède (1803:27 which in turn is a junior synonym *Cheilodipterus* Lacépède 1802 (Opinion 2 1910, Int. Comm. Zool. Nomencl., Smit Publ. No. 1938:55–6) and is thus unava able. Since Lacépède's use of Commerso polynominal manuscript names must rejected (Opinion 89., 1925, Int. Com Zool. Nomencl., Smith. Publ. No. 2830:2 33), *Zingel* Cloquet (1817:240) has prior over *Aspro* Cuvier (*in* Cuvier and Val

iennes, 1828:140). Some authors have lated *Aspro* Cuvier from the *Règne Animal* (Cuvier, 1817) but only the vernacular Les Cingles was used there. Gill (1903), Chevey (1925), and Cărăusu (1952) favored the use of Zingel from Oken (1817) but I reject Oken's Zingel because it, like Sander, is a vernacular usage. *Asperulus* and *Asper* Schaefer (1761) are invalid because Schaefer did not consistently apply the principles of binominal nomenclature (see Jordan, 1917: 16). *Asperulus* Klein, 1774, is invalid because it is not binominal and its reprinting by Walbaum (1792) did not validate it (Opinion 21, Int. Comm. Zool. Nomencl., Smith. Publ. No. 1938:51–2). *Cingla* Stark, 1828, is an additional junior synonym of *Zingel* Cloquet.

Acerina Cuvier (1817:283) is not the valid generic name for the three species of European percids (*acerina, cernua,* and *schraetser*) usually referred to it because *Gymnocephalus* Bloch (1793:24, type species *Perca schraetser* Linnaeus by subsequent designation of Jordan, 1917) is a senior synonym. Jordan (1917:32), who had not seen the reference, referred to *Acerina* Güldenstädt (1774:455), type species *Acerina kabir* Güldenstädt. However, Güldenstädt merely described *Perca acerina* and compared it with *Perca cernua.* There is no mention of a species *kabir* in this paper. *Leptoperca* Gill (1896b:502) is another junior synonym of *Gymnocephalus* Bloch.

Berg (1949) clearly showed that *Zingel* Cloquet and *Gymnocephalus* Bloch were senior synonyms of *Aspro* Cuvier and *Acerina* Cuvier, respectively, but rejected each as being a *"nomen delendum."* There is no provision for such action in the International Code of Zoological Nomenclature. His usage of *Zingel* and *Gymnocephalus* makes it impossible to consider them as *nomina oblita,* and thus *Aspro* and *Acerina* are junior synonyms and cannot be conserved under the provisions of the 50-year rule (Art. 23b, Int. Code Zool. Nomencl., 1961).

Morphology

The anteriormost interhaemal bone (the proximal segment of the radial, Goodrich, 1930; the basal or the proximal radial of the ptergiophore, Eaton, 1945) is much larger than the posterior ones in *Perca, Gymnocephalus,* and *Percarina* (Fig. 1), and noticeably larger in *Percina, Ammocrypta,* and *Etheostoma.* Correlated with this, the anal spines are large and well developed (although they have secondarily become reduced in some of the more specialized species of *Etheostoma*). In *Stizostedion, Zingel,* and *Romanichthys,* the anteriormost interhaemal bone is similar in size to the posterior ones (Fig. 2) and the anal spines are poorly developed. On this basis, the Percidae is divisible into two groups which I believe represent separate phyletic lines that should be regarded as subfamilies. The perches (*Perca, Gymnocephalus, Percarina*) and their specialized derivatives, the darters (*Percina, Ammocrypta, Etheostoma*) comprise the subfamily Percinae (Percini of Bonaparte, 1835). The pikeperches (*Stizostedion*) and their specialized derivatives (*Romanichthys* and *Zingel* form the subfamily Luciopercinae. Most earlier workers have placed the darters apart from the perches; they have either lumped the perches and pikeperches or placed both groups in separate subfamilies. Jordan and Eigenmann (1885) did note that "So far as the cranium is concerned, *Perca* is probably nearer *Percina* than either is to *Stizostedion,*" but neither they nor other workers seem to have realized the significance of their statement.

The earliest available family-group name for the pikeperches appears to be Luciopercinae Jordan and Evermann, 1896 (p. 1018). Hubbs (1926) and Hubbs and Lagler (1947, 1958) also used Luciopercinae. Eddy and Surber (1947:208) applied the name Sandrinae although earlier (1943:108) they used Luciopercinae. Considering the pikeperches congeneric does not invalidate the use of Luciopercinae as a subfamily name because rejecting a nominal type genus does not change the family-group name based on it (Art. 40, Int. Code Zool. Nomencl., 1961). The name Asperulinae Gill (1861a) cannot be used because its type genus, *Asperulus* Klein has no nomenclatural status even though reprinted in Walbaum, 1792 (Opinion 21, 1910, Int. Comm. Zool. Nomencl., Smith. Publ. No. 1938:51–2).

Another character at first seemed to verify the clear separation of the Percinae from the Luciopercinae. From previous accounts (Chevey, 1925; Berg, 1949) and preliminary observations, the lateral line extends well onto the caudal fin in *Stizostedion, Zingel,* and *Romanichthys,* and there are supplementary lateral lines on the caudal fin, one above the main lateral line and another one

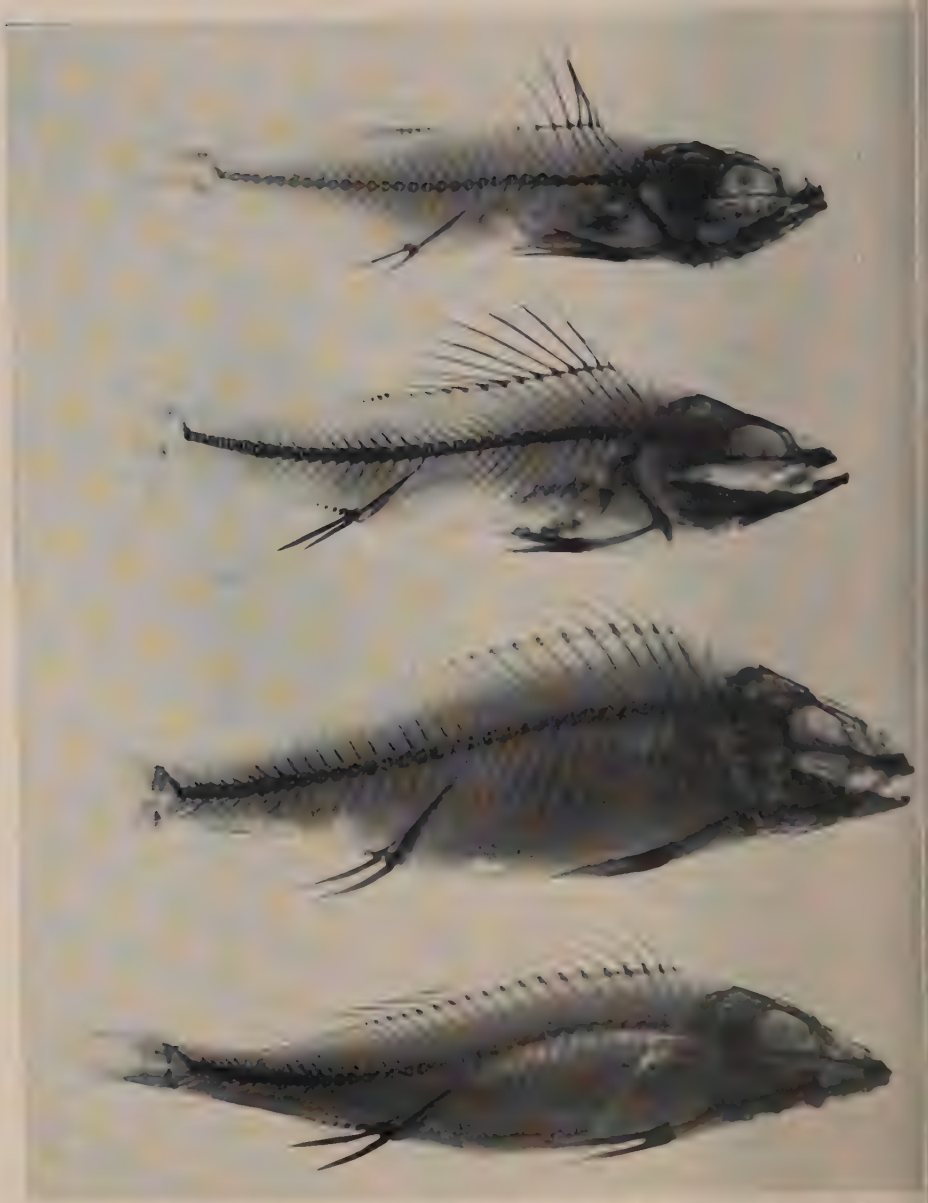

Fig. 1. Radiographs of four species of Percini (from top to bottom) *Percarina demidoffi* USNM 37303, Dnestr R. at Akkerman, USSR, 63 mm S.L. *Perca schrenki*, USNM 21594 Sibe 137 mm S.L. (note vertebral anomalies) *Gymnocephalus cernua*, USNM 119125 Elbe R. Germa 157 mm S.L. *Gymnocephalus schraetser*, USNM 187737, Danube R., Roumania, 149 mm S.L.

below it. In the Percinae, the lateral line usually ends at the base of the caudal fin or continues out onto only a few scales (in some species of *Percina* and *Ammocrypta*) and there are no supplementary lateral lin However, several specimens of *Gymn cephalus schraetser* have supplementary l eral lines. Examination of series of *Ron*

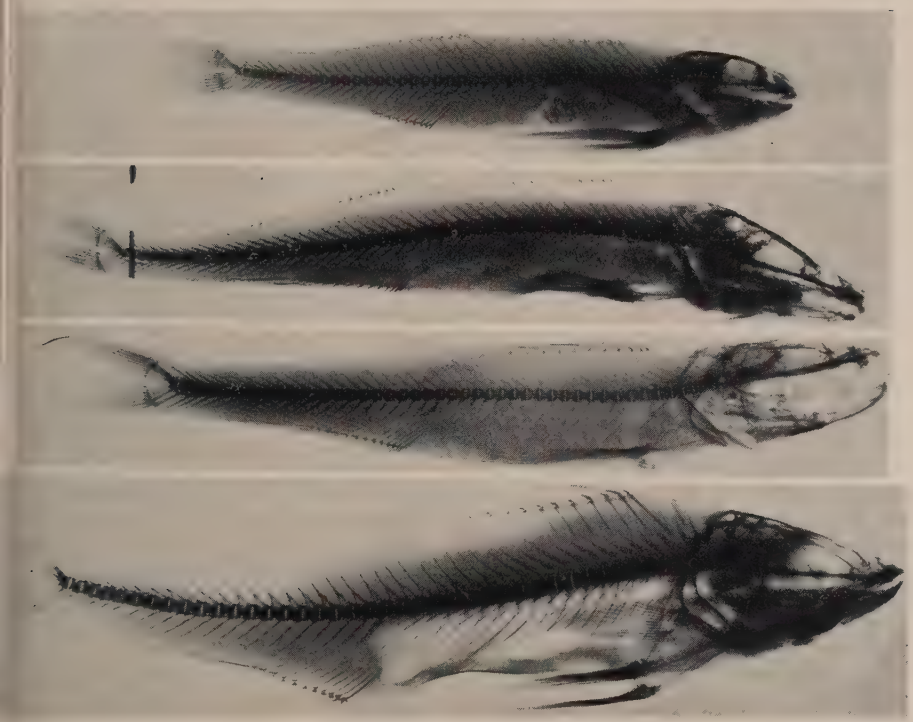

Fig. 2. Radiographs of four species of Luciopercinae (from top to bottom). *Romanichthys valsanicola*, USNM 187752, Arges R., Roumania, 79 mm S.L. *Zingel zingel*, USNM 10720, Europe, 215 mm S.L. *Stizostedion canadense*, USNM 173127, Bayou D'Arbonne, Louisiana, 205 mm S.L. *Stizostedion volgense*, USNM 37256, Oka R., USSR, 245 mm S.L.

nichthys valsanicola revealed that the upper supplementary lateral line, or the lower one, or rarely both, may be absent.

Within each subfamily, selection has acted to produce small, specialized, bottom-dwelling forms with depressed or terete bodies and with the swimbladder reduced or absent. This level of differentiation can best be shown by grouping the most closely related genera of each subfamily into tribes characterized below. The more primitive tribe in the Percinae is the Percini, members of which have well-developed swimbladders and compressed bodies. The Percini includes *Perca, Gymnocephalus* (the Acerinae of Gill, 1861a), and the specialized monotypic *Percarina* (the Percarinae of Gill, 1861a). The second tribe, the Etheostomatini (Etheostomata of Agassiz, 1850) contains the three genera of darters recognized by Bailey (*in* Bailey, Winn, and Smith, 1954; and *in* Bailey and Gosline, 1955), *Percina, Ammocrypta,* and *Etheostoma.* The swimbladder is greatly reduced in *Percina* and is absent in *Ammocrypta* and *Etheostoma* (Morgan, 1936). Osteological characters generally support the above arrangement. The supraoccipital crest is well developed in the Percini, greatly reduced in *Percina* and *Ammocrypta,* and virtually absent in many species of *Etheostoma.* The species of *Perca* and *Gymnocephalus* have an auxiliary interneural bone (terminology of Starks, 1904) anterior to the one supporting the first dorsal fin. Smith and Bailey (1961: 357) have noted the presence of the auxiliary interneural (their predorsal bone) in two forms of *Perca* and one species of *Gymnocephalus.* No auxiliary interneural was present in the few specimens of *Percarina* I have examined. The auxiliary interneural is absent in the species of *Percina, Ammocrypta,* and *Etheostoma* that I have X-rayed or cleared and stained. Smith and Bailey (1961:356) also noted its absence in 14 species of these three genera which they

examined. Also, the first interhaemal bone and the anal spines in the Etheostomatini are not as enlarged as in the Percini.

Similarly, the Luciopercinae can be divided into two tribes, the larger Luciopercini which have the swimbladder and supraoccipital crest well developed and live off the bottom, and the smaller, benthic, Romanichthyini which lack swimbladders, and have the supraoccipital crest reduced. The members of the Luciopercini have an auxiliary interneural bone which is absent in the Romanichthyini.

It might be argued that the characters the Romanichthyini and Etheostomatini have in common (reduced swimbladder, small body size, breeding tubercles, lack of an auxiliary interneural bone) indicate that these two tribes are more closely related to each other than they are to the Luciopercini and Percini. In fact, Dumitrescu, Bănărescu, and Stoica (1957) described the Romanichthyinae for *Romanichthys* and *Aspro* (= *Zingel*) because these genera possessed characters of both the Percinae and the Etheostomatinae. However, I believe that the size of the first interhaemal bone and the anal spines which are similar in the Percini and the Etheostomatini on the one hand, and in the Luciopercini and the Romanichthyini on the other, are more conservative characters than the others and indicate close phylogenetic relationships. The reduced swimbladder and supraoccipital crest in *Percina* and *Ammocrypta* are intermediate evolutionary stages between the well-developed condition in the Percini and absence in the most advanced genus of the Etheostomatini, *Etheostoma*. The similarities between the Etheostomatini and the Romanichthyini are due to convergent evolution resulting from a change from a lentic to a lotic habitat. The reduction in the swimbladders of both groups is a typical adaptation to living on the bottoms of fast-moving streams. There is a striking difference in the distribution of the breeding tubercles between the Romanichthyini and the Etheostomatini. In the former, the tubercles are concentrated on the dorsal and dorsolateral surfaces of the body, and in the latter they are concentrated on the ventral and ventrolateral surfaces (Collette, in press). This seems to indicate an independent origin of tubercles in each tribe. The possession of breeding tubercles on the body is a common characteristic of groups of small-to-moderate-sized fishes living mostly in lotic environments (Collette, in press). The loss of the auxiliary interneural bone in both the Romanichthyini and the Etheostomatini is probably correlated with the general reduction in fin rays and the small body size of these fishes. *Percarina demidoffi*, the smallest member of the Percini also has lost this bone.

Several other characters have been used by various authors to subdivide the Percidae. These include the number of branchiostegal rays, the development of pseudobranchiae, and the presence of a genital papilla. The number of branchiostegals usually is 7 in the Luciopercinae although occasional individuals may have 6. In the Percini, *Perca* usually has 7, occasionally 6, *Gymnocephalus acerina* and *G. cernua* usually have 7, *G. schraetser* has 6 or 7, and *Percarina* has 6 or 8. The Etheostomatini usually have 6 but sometimes 7, and the subgenus *Ulocentra* (of *Etheostoma*) usually has 5. Pseudobranchiae tend to be better developed in the Luciopercinae than in the Percini. They are better developed in the Percini than in the Etheostomatini. Genital papillae are present in the Luciopercinae and in the Percinae (except for *Perca* and perhaps *Percarina*). Genital papillae are best developed in the Etheostomatini and differences in the structure of the genital papilla are useful subgeneric and specific characters in some groups (see, for example, Collette, 1962).

Characteristics of Percid Taxa

Following are definitions of the family and of the subfamilies and tribes that I recognize within the recent Percidae. The characteristics of the family are modified from Regan (1913) and Berg (1955). Vertebral counts (Table 1) are from the material used for this study together with some of the data presented by Bailey and Gosline (1955) and will serve as a supplement to their paper.

Percidae. Percoid fishes generally similar to the Serranidae in having the spinous dorsal fin well developed; the pelvic fins thoracic, with one spine and five branched rays; two nostrils on each side of the head; 5 to 8 branchiostegal rays; four gills, a slit behind the fourth; branchiostegal membranes free from isthmus; villiform and cardiform teeth on upper and lower jaws. Similar to the Centrarchidae and Cichlidae and different from the Serranidae and most

BLE 1. TOTAL NUMBER OF VERTEBRAE (COUNTING THE ULTIMATE CENTRUM AND FUSED HYPURAL AS ONE) IN THE SPECIES OF PERCIDAE (GENERA ONLY OF ETHEOSTOMATINI)

	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
Percini																			
rca flavescens[1]								1	41	24	2								
rca fluviatilis							1	13	15	19	45	4							
rca schrenki[2]					←7		4	——→											
mnocephalus acerina								1											
mnocephalus schraetser							2	15	9										
mnocephalus cernua			34	23	13														
rcarina demidoffi		1	2																
Etheostomatini[3]																			
rcina (20 species)						←——	——	——	——	——	——	——	——	——	——→				
ammocrypta (5 species)							←——	——	——	——	——	——	——	——	——	——	——→		
heostoma (70 species)	←——	——	——	——	——	——	——	——	——	——	——	——	——→						
Luciopercini																			
zostedion vitreum[1]													←—2	16	33	8	——→		
zostedion lucioperca															4	2			
zostedion canadense[1]												1	12	12	5				
zostedion marinum[4]											←——	——	——	——→					
zostedion volgense											1	3	1						
Romanichthyini																			
ngel zingel																2	15	5	
ngel asper												6	2	1					
ngel streber												1	15	8					
omanichthys valsanicola								6	12	1									

[1] Based in part on data presented by Bailey and Gosline (1955).
[2] Nikolsky and Evtukhov (1940) give a range of 36–40 and a mean of 37.4.
[3] Range from data presented for individual species by Bailey and Gosline (1955).
[4] Range from Berg (1949).

her marine percoids in the absence of a ibocular shelf (Smith and Bailey, 1962) id having one or two instead of three anal pines. Different from most percoid families having one or no auxiliary interneural one instead of two or more (Smith and ailey, 1961). Vertebrae 32 to 50. Freshater fishes of the northern hemisphere xcept for North America west of the Rocky lountains (one species, *Etheostoma pottsi*, as crossed the Continental Divide in lexico).

Percinae. Percidae with the anteriormost nterhaemal bone greatly enlarged; anal pines usually large and well developed; lateral line usually not extending onto audal fin and supplementary lateral lines n the caudal fin absent except sometimes n *G. schraetser*.

Percini. Percinae reaching moderate size; upraoccipital crest well developed; auxilary interneural present except in *Percarina;* branchiostegal rays usually 7 or 8; preopercle strongly serrate; genital papilla small or absent; body compressed; anal spines very prominent; swimbladder well developed; breeding tubercles absent; vertebrae 33–43. Three genera: *Perca* Linnaeus (3 species), *Gymnocephalus* Bloch (3 species), and *Percarina* Nordmann (1 species).

Etheostomatini. Percinae reaching small to moderate size; supraoccipital crest greatly reduced; auxiliary interneural absent; branchiostegal rays usually 5 or 6; preopercle entire or partially serrate; genital papilla usually well developed in females; body slightly compressed or fusiform; anal spines usually moderately prominent; swimbladder reduced or absent; breeding tubercles present in males of some species of all genera; vertebrae 32–48. Three genera: *Percina* Haldeman (20 valid described species), *Ammocrypta* Jordan (5 species), and *Etheostoma* Rafinesque (more than 74 species).

Luciopercinae. Percidae with the anteriormost interhaemal not larger than posterior

interhaemals; anal spines weak; lateral line extending onto caudal fin with supplementary lateral lines above and below it (one or both supplementary lateral lines sometimes absent in *Romanichthys*).

Luciopercini. Luciopercinae reaching large size; nasal flap slightly developed on anterior nostril, absent on posterior; maxillary free posteriorly; well-developed canine teeth present except in *S. volgense*; swimbladder well developed; auxiliary interneural bone present, supraoccipital crest well developed; body slightly compressed; breeding tubercles absent; vertebrae 42–50. One genus, *Stizostedion* Rafinesque with five species.

Romanichthyini. Luciopercinae reaching small to moderate size; nasal flaps well developed on both anterior and posterior nostrils; maxillary concealed posteriorly; canine teeth absent; swimbladder absent; auxiliary interneural bone absent; supraoccipital crest moderately developed; body depressed or fusiform; breeding tubercles developed in both sexes; vertebrae 39–49. Two genera: *Zingel* Cloquet (3 species) and *Romanichthys* Dumitrescu, Bănărescu, and Stoica (1 species).

Literature Cited

Agassiz, Louis. 1850. Lake Superior: Its physical character, vegetation, and animals, compared with those of other and similar regions. *Gould, Kendall and Lincoln, Boston 428 p.*

Bailey, R. M. and W. A. Gosline. 1955. Variation and systematic significance of vertebral counts in the American fishes of the family Percidae. *Misc. Publ. Mus. Zool. Univ. Mich. 93:1–44.*

———, H. E. Winn, and C. L. Smith. 1954. Fishes from the Escambia River, Alabama and Florida, with ecologic and taxonomic notes. *Proc. Acad. Nat. Sci. Phila. 106:109–64.*

Berg, L.S. 1949. The fishes of the freshwaters of the USSR and the surrounding territory. *Opredel. Faun. SSSR, Zool. Inst. Akad. Nauk SSSR, no. 30, part 3:929–1381. (In Russian.)*

———. 1955. Classification of fishes and fish-like vertebrates, both recent and fossil. *2nd. ed. Akad. Nauk SSSR, Moskva, 286 p. (In Russian.)*

Bloch, M. E. 1793. Naturgeschichte der Aüslandischen Fische. *Vol. 7. Königl. Akad. Berlin 144 p.*

Bonaparte, C. L. 1835. Iconografia della fauna Italica per le quattro classi degli animali vertebrati. *Tomo III. Pesci. Fasc. 14, 17.*

Cărăusu, S. I. 1952. Tratat de ichtiologie. *Acad. Rep. Pop. Romine, Bucharest 804 p.*

Chevey, P. 1925. Recherches sur la perche et le bar, étude embryogénique, systématique et biogéographique des percidés Européens. *Bull. Biol. France, Belgique 59(2):145–292.*

Cloquet, Hippolyte. 1817. Cingle, *Zingel*. *Dictionnaire Sci. Nat., Paris 9:240–1.*

———. 1827. Sandre, *Sandat*. *In Dictionnaire Sci. Nat., Paris 47:173–5.*

Collette, B. B. 1962. The swamp darters of the subgenus *Hololepis* (Pisces, Percidae). *Tulane Stud. Zool. 9(4):115–211.*

———. In press. Breeding tubercles in fishes, with special reference to their systematic significance in the Percidae.

——— and R. W. Yerger. 1962. The American percid fishes of the subgenus *Villo*. *Tulane Stud. Zool. 9(4):213–30.*

Cuvier, Georges. 1817. Le règne animal distribué d'après son organisation. *Vol. II, Pa 532 p.*

——— and Achille Valenciennes. 1828, 18 Histoire naturelle des poissons. *Vol. 2, 370 Vol. 3, 368 p., Leurault, Paris.*

Dumitrescu, Margareta, Petru Bănărescu, and Nicolae Stoica. 1957. *Romanichthys valsanicola* nov. gen. nov. sp. (Pisces, Percida *Trav. Mus. Hist. Nat. "Gr. Antipa" 1:225–*

Eaton, T. H., Jr. 1945. Skeletal supports of the median fins of fishes. *J. Morph. 76(*
193–212.

Eddy, Samuel and Thaddeus Surber. 19 1947 (Rev. ed.). Northern fishes. *Un Minn. Press, 252 p. (276 p. in rev. ed.).*

Fleming, John. 1822. The philosophy of ology. *Vol. II, Archibald Constable & Edinburgh 618 p.*

Gill, Theodore. 1861a. Synopsis of the subfamily of Percinae. *Proc. Acad. Nat. Phila. 1861:44–52.*

———. 1861b. Synopsis of the sillaginoids. *Proc. Acad. Nat. Sci. Phila. 1861:501–7.*

———. 1894. On the relations and nomenclature of *Stizostedion* or *Lucioperca*. *U. S. Natl. Mus. 17(993):123–8.*

———. 1903. On some fish genera of the first edition of Cuvier's Règne Animal and Oken's names. *Proc. U. S. Natl. Mus. 26(1346):961*

Goodrich, E. S. 1930. (1958 reprint). Studies on the structure and development of vertebrates. *Reprint edition by Dover Publ., New York, Vol. 1 485 p.*

Güldenstädt, A. I. 1774. Acerina; piscis, percae genus pertinens, descriptus. *Commentarii Acad. Sci. Imp. Petropolitanae 19:455–62.*

Hubbs, C. L. 1926. A check-list of the fishes of the Great Lakes and tributary waters, with nomenclatorial notes and analytic keys. *Publ. Mus. Zool. Univ. Mich. 15:1–77.*

——— and K. F. Lagler. 1947, 1958 (rev. ed.). Fishes of the Great Lakes region. *Cranbrook Inst. Sci. Bull. 26, 186 p. (213 p. in rev.*

Jordan, D. S. 1877. Contributions to North American ichthyology. . . . II. A. Notes on Cottidae, Etheostomatidae, Percidae, Catarchidae, Aphododeridae, Dorysomatidae and Cyprinidae. . . . *Bull. U. S. Natl. Mus. 10:5–68.*

———. 1917. The genera of fishes from Linnaeus to Cuvier, 1758–1833. *Stanford Univ. Publ., Univ. Ser. 161 p.*

———. 1923. A classification of fishes including families and genera as far as kno

Stanford Univ. Publ., Univ. Ser. Biol. Sci. 3(2):77–243.

—— AND C. H. EIGENMANN. 1885. Notes on skeletons of Etheostomatinae. *Proc. U. S. Natl. Mus. 8(484):68–72.*

—— AND B. W. EVERMANN. 1896. The fishes of North and Middle America. *Bull. U. S. Natl. Mus. 47, part 1 1240 p.*

LACÉPÈDE, BERNHARD. 1802 (Vol. 3), 1803 (Vol. 4). Histoire naturelle des poissons. *Plassan 558 p. (Vol. 3), 728 p. (Vol. 4).*

MORGAN, G. D. 1936. A study of the vestigial air bladder in the darter (*Catonotis* [sic] *flabellaris* Rafinesque). *J. Sci. Labs. Denison Univ. 31(4–6):143–58.*

NIKOLSKY, G. V. AND N. A. EVTUKHOV. 1940. The fishes of the middle and lower courses of the Ili River. *Bull. Mosk. Obsch. Isp. Prir., Biol. 49(5–6):57–70. (In Russian.)*

OKEN, LORENZ. 1816. Lehrbuch der Naturgeschichte. Theil 3, Zool., Abth. 2, Fleischthiere. *Jena 1270 p.*

———. 1817. Cuvier's und Oken's zoologien naben einander gestellt. *Isis, Encyclo. Zeitung 8(148):1179–85.*

RAFINESQUE, C. S. 1820. Ichthyologia Ohiensis. *Reprinted in Richard E. Call, 1899, Burrows Brothers Co., Cleveland p. 40–162.*

REGAN, C. T. 1913. The classification of the percoid fishes. *Ann. & Mag. Nat. Hist. ser. 8 12:111–45.*

SCHAEFFER, J. C. 1761. Piscium Bavarico-Ratisbonensium pentas. . . . *Ratisbonae 82 p.*

SCHINZ, H. R. 1822. Das Thierreich . . . Naturgeschichte . . . von Cuvier. . . . *Vol. 2, Stuttgart 835 p.*

SMITH, C. L. AND R. M. BAILEY. 1961. Evolution of the dorsal-fin supports of percoid fishes. *Paps. Mich. Acad. Sci., Arts, Lett. 46: 345–63.*

———. 1962. The subocular shelf of fishes. *J. Morph. 110(1):1–18.*

STARK, JOHN. 1828. Elements of natural history. *Vol. 1, Vertebrata. Blackwood, Edinburgh.*

STARKS, E. C. 1904. The osteology of some berycoid fishes. *Proc. U. S. Natl. Mus. 27 (1366):601–19.*

WALBAUM, J. J. 1792. Petri Artedi sueci genera piscium . . . ichthyologiae pars III. *Grypeswaldiae 723 p.*

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Methodological Paper No. 1A

A PRELIMINARY REVIEW OF THE FISHES OF THE FAMILY SCOMBRIDAE

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1 INTRODUCTION

1.1 Importance of the taxonomy of the Scombridae

In addition to the usual evolutionary interest, the taxonomy of the Scombridae is especially important because of the vital role of the tunas and mackerels in world fisheries. A number of the species migrate long distances and thus come into the catches of different fisheries. It is therefore necessary to know more about the species and their populations to manage the fisheries rationally. The taxonomy of the family must be clearly established, so that excessive name-changing will not further complicate the accumulation of data on the various members of the family.

This paper was prepared in response to Resolution No. 1 of the Pacific Tuna Biology Conference held in Honolulu, Hawaii in August, 1961.

1.2 Problems of taxonomy in the Scombridae

Several factors have made the taxonomy of the Scombridae more difficult than that of many other families. The large size of many species, especially of some of the tunas, makes it difficult if not impossible, to store the large series necessary for thorough taxonomic work. Many observations, therefore, have to be made at the time of collection, often under adverse conditions and, as the specimens usually must be disposed of, there is no opportunity of checking the accuracy of these observations. Many species of Scombridae are wide-ranging, with some of the tunas having world-wide distributions. Thus workers have been virtually forced to confine their studies to only a portion of the range of a given species. This provincialism has led to the description of too many species in many of the genera. Many of the easily countable structures in the scombrids are very similar from species to species within a genus. Thus, morphometrics have been extensively used to separate species and sub-populations. Some of the scombrids reach large sizes which make changes due to growth difficult to evaluate. The search for characters has led, in the tunas, to the use of internal characters in the osteology, circulatory system, and position of the viscera. The use of the patterns of the circulatory system usually requires the use of fresh or frozen specimens, which makes the task of obtaining the adequate material still m difficult.

2 THE FAMILY SCOMBRIDAE

Regan (1909) defined the family Scombridae and distinguished it from related families such as the Gempylidae Trichiuridae, Luvaridae, Istiophoridae and Xiphiidae. Kishinouye (especiall 1915 and 1923) divided the Scombridae into four families: Scombridae, Cybi Katsuwonidae and Thunnidae, the last of which he recognized as the order Plecostei, separate from all other hi er bony fishes (which he called Telec He based these decisions upon detaile anatomical work on the Japanese scomb Although he was an excellent anatomis his taxonomic conclusions were poor, Berg (1940, 1955) is the only present ichthyologist of note to separate the tunas (under the name Thunniformes). Takahasi (1926) early pointed out th the subcutaneous circulatory system the "Plecostei" was not unique, as K nouye had claimed, and so invalidate "order". Starks (1910), Fraser-Brun (1950), and also the present authors work indicates that the Scombridae i natural family.

3 THE GENERA AND SPECIES OF SCOMBR

3.1 Introduction

The generic status of the member this family has vacillated back and from the extremes of several very la genera to many monotypic or oligotyp genera. The genera that the present thors recognize will be discussed br below. These are the same as those recognized by Fraser-Brunner (1950), b we feel that our arrangement is a cl approach to a natural phylogenetic c The species utilized here should be sidered tentative in all genera exce *Thunnus*.

3.2 *Gasterochisma* Richardson

This monotypic genus (*G. melamp* Richardson) has been placed in a sep ate sub-family, the Gasterochismatin by Fraser-Brunner (1950) because of large cycloid scales, lack of cauda keels, and other characters. It is

rent from the Scombrinae that it ave to be placed in a separate y.

.3 *Scomber* Linnaeus

3.3.1 Status of *Pneumatophorus* Jordan and Gilbert

he authors agree with Fraser-Brunner) that *Pneumatophorus* is a synonym *omber*. The presence of an air blad- ometimes varies even within a spe- in the Scombrinae, so this does not to be a valid generic character.

3.3.2 Position of *Scomber*

Scomber and *Rastrelliger* appear to e most primitive genera of the sub- ly Scombrinae. They are fully scaled, a low number of vertebrae (31), have small keels on the side of the caudal ncle, and the dorsal fins are widely rated.

3.3.3 Species of *Scomber*

Fraser-Brunner (1950) recognized only species; the cosmopolitan *S. japonicus* tuyn, which has an air-bladder, and Atlantic-Mediterranean *S. scombrus* aeus, which lacks an air-bladder. cop (1958) distinguished an addition- pecies in the Philippine Islands, *ustralasicus* Cuvier, on the basis of ter body depth, larger scales, and a compressed body. In these charac- , *S. australasicus* is more closely ted to *Rastrelliger* than either of other two species of *Scomber*.

During the discussion C.L. Hubbs and Fitch (U.S.A.), and I.A. Ronquillo lippines), agreed that there are two ies of *Scomber* in the Pacific. ostel (France) pointed out that *ber japonicus* shows striking geogra- al variations in body size down the can coast. Additional study is need- o explain this phenomenon.

3.4 *Rastrelliger* Jordan and Dickerson

This genus differs from *Scomber* pri- ly in having numerous greatly elonga- feather-like gill-rakers as well as ng larger scales and a more com- sed body. Fraser-Brunner (1950) gnized two species: *R. canagurta* ier) and *R. brachysoma* (Bleeker). g the same characters -- number of gill rakers and body depth -- Manacop (1958) also distinguished two species of *Rastrelliger* in the Philippines but used a junior synonym, *chrysozonus* Rüppel, instead of *canagurta* Cuvier.

Ronquillo supported Manacop's (1958) statement during the discussion.

3.5 *Scomberomorus* Lacépède

3.5.1 Generic synonyms

Munro (1943) divided this genus into nine subgenera: *Scomberomorus* Lacépède, *Cybium* Jordan and Hubbs, *Sawara* Jordan and Hubbs, *Pseudosawara* Munro, *Indocybium* Munro, *Sierra* Fowler, *Chriomitra* Lockington, *Cybiosarda* Whitley, and *Lepidocybium* Gill. Later Munro (1949) removed *Lepidocybium flavobrunneum* (Smith) from the Scombridae and, on the basis of its caudal structure, placed it in the Gempylidae. Fraser-Brunner (1950) recognized only *Scomberomorus* and *Cybium* as subgenera. Mago-Leccia (1958) hypothesized that on osteological grounds *Scomberomorus* may be divisible into two subgenera.

3.5.2 Species of *Scomberomorus*

Munro (1943) recognized a total of 17 species in the genus and then (1949) made it 16 by subtracting *L. flavobrunneum*. Fraser-Brunner (1950) recognized only 9 species. Additional work is plainly needed to clarify this situation.

3.6 *Grammatorcynus* Gill

This monotypic Indo-Pacific genus [*G. bicarinatus* (Quoy and Gaimard)] is closely related to *Scomberomorus*. It differs primarily in having two lateral lines and fewer vertebrae.

3.7 *Acanthocybium* Gill

This is another monotypic subgenus [*A. solandri* (Cuvier)] that has been derived from *Scomberomorus*. It has completely lost its gill rakers, the vertebrae are increased to 54-66 (Conrad 1938), and its jaws are beak-like. Mago-Leccia (1958) also pointed out the relatively close relationships between *Acanthocybium* and *Scomberomorus*.

3.8 *Orcynopsis* Gill

This monotypic subgenus, together with the next one (*Gymnosarda*), forms a link between the more primitive and the more advanced members of the Scombrinae. Both genera have a moderately low number of vertebrae (38). *Orcynopsis unicolor* (Geoffrey St. Hilaire) is limited to the eastern Atlantic and Mediterranean.

Postel stated that these two genera were very closely related and might be considered congeneric.

3.9 *Gymnosarda* Gill

The sub-family Scombrinae can be divided into two subgroups at this point. *Scomber, Rastrelliger, Scomberomorus, Grammatorcynus,* and *Acanthocybium* have caudal notches and lack bony caudal keels. *Orcynopsis, Gymnosarda, Sarda, Auxis, Euthynnus, Allothunnus,* and *Thunnus* lack caudal notches and have bony caudal keels. *Gymnosarda* is characterized by the possession of large conical teeth that are curved forward. Fraser-Brunner (1950) recognized two species in this genus: *G. elegans* (Whitley) and *G. unicolor* (Rüppell).

3.10 *Sarda* Cuvier

3.10.1 Generic position

Sarda differs from the four more advanced genera in lacking a cutaneous circulatory system and in lacking prootic pits (Godsil 1954). There are more vertebrae (44-52) in *Sarda* than in any of the other members of the more advanced sub-group (36-41).

3.10.2 Species of *Sarda*

Godsil (1955) recognized two species complexes within *Sarda*: the *Sarda chiliensis* complex characterized by gill-teeth developed on the first gill-arch, 20-27 gill-rakers, and 20-25 teeth on each side of the lower jaw, and the *orientalis-velox* complex characterized by a lack of gill-teeth, only 8-13 gill-rakers, and only 10-15 teeth on each side of the lower jaw.

Mather pointed out that the Atlantic and Pacific populations of *Sarda* must be considered distinct because of differences in vertebrae counts, *Sarda sarda* in the western Atlantic having about 52, and the eastern Pacific forms having about 44.

De Vildoso (1955, 1962) felt the[re] were two distinct species in the eas[t]ern Pacific: *Sarda velox* and *Sarda chiliensis*. She further indicated t[he] possibility that the disjunct popula[t]ions of *Sarda chiliensis* might repr[e]sent two sub-species: *Sarda chilien[sis] lineolata* on the coast of California and Mexico with an average of one mo[re] vertebra than *Sarda chiliensis chiliensis* along the coast of South America.

Klawe (as noted by Rivas, 1951) [sug]gested that Breder's (1932) referenc[e] the occurrence of *Sarda velox* in the Atlantic off Block Island might be [an] error.

If four nominal species be recog[n]ized, they would be: *Sarda sarda* [in] the Atlantic and Mediterranean, *Sarda velox* and *S. chiliensis* in the easte[rn] Pacific, and *Sarda orientalis* from [the] western Pacific and Indian Ocean.

3.11 *Allothunnus* Serventy

This monotypic genus is the most recently described (Serventy 1948) [in] the Scombridae. *Allothunnus fallai* [dif]fers strikingly from all other scombr[ids] in its great number of gill-rakers (7[0]-75; Serventy 1948, and Talbot 1960). The other scombrids vary from 0 (in *Acanthocybium*) to 53-63 (in *Euthynnus pelamis*).

Talbot mentioned that a second [spe]men of *Allothunnus* had been taken in South Africa. The genus lacks a sub-cutaneous vascular system and the [pos]parietal foramina, as found in *Euthy[nnus]* and *Thunnus*. Furthermore, prootic [pits] are present but are not as marked as [in] *Auxis, Euthynnus,* or *Thunnus*. An [ante]or corselet is present, and scaling [be]hind this is variable (Talbot in pre[ss]).

3.12 *Auxis* Cuvier

3.12.1 Generic position

Auxis is the most primitive of [the] higher tunas to have developed a pro[to]pit and a partial subcutaneous circula[to]ry system. It differs from the t[wo] more advanced genera (*Euthynnus* and *Thunnus*) by lacking the prominent [pos]parietal foramina present in the cran[ium] of that group. It is similar to *Euthynnus* in having a naked body bein[d] the well-developed corselet.

There are 39 vertebrae in *Auxis*, as in *Thunnus*. The two dorsal fins are widely separated in *Auxis*, as in the much more primitive genera *Scomber* and *Rastrelliger*.

3.12.2 Species of *Auxis*

Fraser-Brunner (1950) recognized only a single world-wide species, *A. thazard* (Lacépède). At about the same time, Wade (1949) distinguished an additional species, a long-corseleted Pacific form, *A. tapeinosoma* Bleeker. Matsumoto (1960) has recently resurrected the name *A. thynnoides* Bleeker to apply to the long-corseleted form of the western Pacific. He placed the names *A. hira* and *A. maru* Kishinouye, together with *tapeinosoma* Bleeker, as synonyms of the short-corseleted, world-wide *A. thazard*. Fitch and Roedel (1962) tentatively recognize two world-wide species, *A. rochei* Risso and *A. thazard*, on the basis of dorsal pattern, width of corselet under the second dorsal, position of the anterior end of the dorsal bare area with respect to the pectoral tip, several skeletal features, and, possibly, pored lateral-line scale counts. Fitch pointed out a habitat difference between these two species, *A. rochei* being found close to land and *A. thazard* being found typically off shore, at least in the eastern Pacific.

3.13 *Euthynnus* Jordan and Gilbert

3.13.1 Generic position

A number of recent authors have recognized two genera: the monotypic *Katsuwonus* Kishinouye for the skipjack (*E. pelamis*), and *Euthynnus* for the little tunas (Godsil and Byers 1944; Fraser-Brunner 1949; Rivas 1951; Godsil 1954). In other papers (e.g., Fraser-Brunner 1950) *Katsuwonus* has been considered as a subgenus of *Euthynnus*. Their close relationship has been emphasized by Kishinouye (1923), Godsil (1954), and others who have followed Kishinouye's classification, where *Katsuwonus* and *Euthynnus* are placed in the "Katsuwonidae" together with *Auxis*. Externally, *E. pelamis* differs from other species of *Euthynnus* by the lack of black markings above the lateral line and the presence of longitudinal, oblique, black stripes on the silvery belly. Internally, *E. pelamis* is more advanced than other members of *Euthynnus* in having the dorsal and ventral branches of the cutaneous artery about equally developed. In *Euthynnus* proper, the ventral branch is short and dendritic (Godsil 1954). There are slightly more vertebrae in *E. pelamis* (41) than in the other species of *Euthynnus* (36-39); however, in spite of the differences that exist between *Katsuwonus* and *Euthynnus*, the present authors think it more indicative of relationships to unite the two into a single genus, as done by Fraser-Brunner (1950). This choice is based largely on the separation of *Euthynnus* from *Auxis* on the one hand (fronto-parietal foramina absent in *Auxis*) and *Thunnus* on the other (well-developed subcutaneous circulatory system and first vertebra ankylosed to skull in *Thunnus*).

3.13.2 Species of *Euthynnus*

Fraser-Brunner (1949, 1950) recognized two species, *E. affinis* (Cantor) and *E. alletteratus* (Rafinesque) in addition to the skipjack *E. pelamis* (Linnaeus). Fraser-Brunner (1949) divided *E. affinis* into three subspecies: *E. affinis affinis* (Cantor) from the Red Sea, Indian Ocean, Australia, Thailand, and Formosa; *E. a. yaito* Kishinouye from Japan, Hawaii, and Pacific islands; and *E. a. lineatus* Kishinouye from the Pacific Ocean off Central America. Present evidence indicates that *E. lineatus* may be a valid species while *E. yaito* may best be considered as a synonym of *E. affinis*. Fraser-Brunner (1949) described a new subspecies *E. alletteratus aurolitoralis* from Ghana. This appears to be a color variant within the range of variations in *E. alletteratus* and should be synonymized with it.

3.14 *Thunnus* South

3.14.1 Introduction

There is at least one generic name available for all but one of the six species of *Thunnus* that are recognized by the present authors: *Thunnus* for the bluefin tuna, *T. thynnus*; *Germo* Jordan for the albacore, *T. alalunga*; *Neothunnus* Kishinouye for the yellowfin, *T. albacares*; *Parathunnus* Kishinouye for the bigeye, *T. obesus*, and blackfin, *T. atlanticus*; and *Kishinoella* Jordan and Hubbs for the longtail, *T. tonggol*. Except for Jordan and Evermann (1926), most reviews of the great tunas have placed *Germo* in the synonymy of *Thunnus*. However, the majority of recent workers have recognized

Thunnus, *Neothunnus*, *Parathunnus*, and *Kishinoella*, either as genera (Godsil and Byers, 1944; Godsil, 1954) or subgenera (Fraser-Brunner, 1950; Rivas, 1961). However, the present authors feel that the differences between all of these "genera" are specific and not generic differences (Gibbs and Collette, MS) and thus follow such authors as Rivas (1951) and de Sylva (1955).

3.14.2 Species of *Thunnus*

3.14.2.1 The bluefin tuna, *Thunnus thynnus* (Linnaeus)

Different authors recognize varying numbers of species or sub-species in what we believe to be one world-wide species. Ginsburg (1953) has presented the most extreme viewpoint in the recent literature, recognizing an eastern Atlantic bluefin, *T. thynnus;* a western Atlantic *T. secundodorsalis* (Storer); and an eastern Pacific *T. saliens* Jordan and Evermann. He did not discuss the Japanese population, for which the name *T. orientalis* (Temminck and Schlegel) is available, or the Australian population, *T. maccoyii* (Castelnau). These were all considered as synonyms of *T. thynnus* by Fraser-Brunner (except that he placed *T. maccoyii* in the synonymy of *T. obesus*, a mistake rectified by Godsil and Holmberg, 1950). On the basis of anatomical characters (bulge in roof of body cavity, shape of air-bladder, gill-rakers, etc.), Godsil and Holmberg (1950) recognized the Australian *T. maccoyii* as a species separate from an Atlantic-California coast *T. thynnus*. Serventy (1956a) has expressed the view that there are six isolated populations within the single world-wide species *T. thynnus*. On the basis of number of gill-rakers and other characters, we feel that there is justification for separating an Atlantic subspecies (*T. thynnus thynnus*) from an Indo-Pacific subspecies (*T. thynnus orientalis*), but that further sub-divisions should not be recognized by formal nomenclature. In this respect the present authors agree with Jones and Silas (1960). Talbot and Penrith (1962a, b) state that large populations of *Thunnus thynnus orientalis* occur west of Cape Town in the southern winter, while a few large specimens of *Thunnus thynnus thynnus* are taken in the same area in the summer months.

3.14.2.2 The bigeye tuna *Thunnus obesus* (Lowe)

Current opinion is divided as to whether the Atlantic form (*obesus*) is different from the Indo-Pacific form (*sibi* Schlegel 1844, or *mebachi* Kishinouye 1923). Fraser-Brunner (1950) synonymized *sibi* and *mebachi* under *obesus*. He also erroneously put *T. maccoyii* Castelnau, *T. phillipsi* Jordan and Evermann, and *Parathunnus rosengarteni* Fowler in the synonymy of *T. obesus* (corrected by Rivas, 1961). Jones and Silas (1960) recognized the Indo-Pacific form as *Parathunnus obesus mebachi*. (The name *sibi* has priority over *mebachi*, so their subspecific name is incorrect if the forms were different.) Rivas (1961) considered *obesus* and *sibi* as valid species, distinguishing them on the basis of pectoral fin length. We find this character to be very variable and consider the Indo-Pacific and Atlantic forms to be conspecific. Frade (1960) has recently reviewed the literature on the eastern Atlantic population of *T. obesus*. Talbot and Penrith (1926a, b) have shown a continuous distribution of this species around the Cape of Africa in summer.

3.14.2.3 The yellowfin tuna *Thunnus albacares* (Bonnaterre)

Due mainly to proportional differences, there is more confusion about this species than others in the genus. Jordan and Evermann (1926) recognized six species: *Neothunnus catalinae* Jordan and Evermann from southern California; *N. macropterus* (Schlegel) from Japan to Hawaii; *N. albacora* (Lowe) from Madeira; *N. itosibi* Jordan and Evermann from Hawaii and Japan; *N. albacores* [sic] (Bonnaterre) from Madeira and the West Indies; and *N. allisoni* (Mowbray) from Florida. The main differences between these forms are in the relative lengths of the second dorsal and anal fins. Fraser-Brunner (1950) placed these names in the synonymy of *T. albacora* (Lowe), although the name *albacares* (Bonnaterre) clearly has priority. Most workers have not completely agreed with him, usually recognizing the Indo-Pacific species (*macropterus*) as distinct from the Atlantic (*albacares*).

mple, Ginsburg (1953) recognized pecies based on the relative of the second dorsal and anal *T. albacares* from the eastern ic; *T. subulatus* (Poey) from the n Atlantic; *T. catalinae* from the n Pacific; and *T. macropterus* from ntral and western Pacific. Rivas has indicated and Royce (1961) own conclusively that there is single pantropical species with a uous distribution. Talbot and h (1962a, b) have shown a continu- stribution of this species around p of Africa in summer.

3.14.2.4 The albacore, *Thunnus alalunga* (Bonnaterre)

rdan and Evermann (1926) recognized cific albacore as a distinct species Lacépède) from the Atlantic alba- *alalunga*). Most recent workers oncluded that the albacore is a world-wide species (Fraser-Brunner, Rivas, 1951; etc.) and the studies present authors confirm this. and Penrith (1962a, b) report that species is common west of Cape Town ghout the year.

3.14.2.5 The blackfin tuna, *Thunnus atlanticus* (Lesson)

his small Atlantic tuna has been sed with both the albacore, *T.* *nga*, and the bigeye, *T. obesus* r-Brunner (1950). Beebe and Tee- 1936) were the first to reaffirm ly its distinctness, although this pparently overlooked by Fraser- er. This was further confirmed by (1951, 1961) and Bullis and Mather) on the basis of the moderately pectoral fin, low number of gill- s (20-24), and color of the finlets, and by de Sylva (1955), who studied steology and relationships of *T.* *ticus*. Our studies further confirm pecific distinctness.

3.14.2.6 The longtail tuna, *Thunnus tonggol* (Bleeker)

his Indo-Pacific species of tuna is east known member of the genus. n and Evermann recognized three es: *Neothunnus tonggol* from Java; *noella rara* (Kishinouye) from Japan and *K. zacalles* Jordan and Evermann from Hawaii. The present authors (MS), found that *K. zacalles* has too many gill-rakers to be identified as *T. tonggol* and best fits the description of *T. albacares*. The longtail tuna (and the nominal "genus" *Kishinoella*) are characterized by the absence of a swim bladder, a low number of gill-rakers, and differences in body proportions. Serventy (1942) presented an account of the anatomy of this species and synonymized *T. rarus* and *T. nicholsoni* Whitley with it. Fraser-Brunner (1950) followed Serventy (1942). Serventy (1956b) presented further information on the Australian populations of *T. tonggol*, and Jones and Silas (1960) recorded it from various localities in the Indian Ocean.

4 CONCLUSIONS

Although the general outline is fairly clear, there are a number of problems in the present classification of the Scombridae. Extensive international cooperation is needed to obtain the specimens to solve the existing taxonomic problems. The present authors are now completing a manuscript that will clarify the species and generic status of the genus *Thunnus*. Royce (1961) has completed a morphometric study of the yellowfin tuna, *Thunnus albacares*. Fitch and Roedel (1962) have presented a review of the frigate mackerels, genus *Auxis*. We hope that other workers will be interested in clarifying other problem areas within the family such as (1) the number of species of *Scomberomorus*; (2) the number of species and/or subspecies of mackerels, *Scomber*; (3) the number of valid forms of bonitos, *Sarda*; and (4) the family-subfamily-tribal level of classification of the group.

5 REFERENCES

Beebe, W. and J. Tee-Van, Systematic notes on Bermudian and West Indian
1936 tunas of the genera *Parathunnus* and *Neothunnus*. Zoologica, N.Y., 21(3):177-94

Berg, L.S., Classification of fishes and fishlike animals, both recent and
1940 fossil. Trud.zool.Inst.Akad. Nauk SSSR, 5(2):87-345

_____, Classification of fishes and fishlike animals, both re-
1955 cent and fossil. 2nd ed., Trud.zool. Inst.Akad. Nauk SSSR, 20:286 p.

Breder, C.M., A record of *Sarda velox* and notes on other Block Island
1932 fishes. Copeia (1):31-32

Bullis, H.R., Jr. and F.J. Mather III, Tunas of the genus *Thunnus* of the
1956 northern Caribbean. Amer.Mus.Novit., (1765):12 p.

Conrad, G.M., The osteology and relationships of the wahoo (*Acanthocybium*
1938 *solandri*), a scombroid fish. Amer.Mus.Novit., (1000):32 p

de Sylva, D.P., The osteology and phylogenetic relationships of the blackfi
1955 tuna, *Thunnus atlanticus* (Lesson). Bull.Mar.Sci.Gulf Caribb., 5(1):1-41

de Vildoso, C.A., Estudio preliminar sobre el "bonito" *Sarda chilensis*
1955 (C y V) de la costa del Perú. Pesca y Caza, (6):1-38

* _____, Especies del genero *Sarda* en el Pacifico oriental.
1962 Experience Paper No. 32

*Fitch, J.E. and P.M. Roedel, A review of the frigate mackerels (genus *Auxi*)
1962 of the world. Experience Paper No. 18

Frade, F., Le thon patudo *Parathunnus obesus* (Lowe) et sa peche. Estud.
1960 Yta.Invest.Ultramar, (69):74 p.

Fraser-Brunner, A., On the fishes of the genus *Euthynnus*. Ann.Mag.nat.Hi
1949 12(2):622-7

_____, The fishes of the family Scombridae. Ann.Mag.nat.Hist.
1950 12(3):131-63

Ginsburg, I., The taxonomic status and nomenclature of some Atlantic and
1953 Pacific populations of yellowfin and bluefin tunas. Copeia (1):1-10

Godsil, H.C., A descriptive study of certain tuna-like fishes. Fish Bull,
1954 Sacramento, (97):188 p.

_____, A description of 2 species of bonito *Sarda orientalis* a
1955 *S. chiliensis* and a consideration of relationships within the genus. Fish Bull.,Sacramento, (99):43 p.

ısil, H.C. and R.D. Byers, A systematic study of Pacific tunas. Fish
1944 Bull.,Sacramento, (60):131 p.

ısil, H.C. and E.K. Holmberg, A comparison of the bluefin tunas, genus
1950 *Thunnus* from New England, Australia and California. Fish Bull.,Sacramento, (77):55 p.

ıes, S. and E.G. Silas, Indian tunas - A preliminary review, with a key
1960 for their identification. Indian J.Fish., 7(2):369-93

rdan, D.S. and B.W. Evermann, A review of the giant mackerel-like fishes,
1926 tunnies, spearfishes and swordfishes. Occ.Pap.Calif.Acad. Sci., (12):1-113

shinouye, K., A study of the mackerels, cybiids, and tunas. Proc.sci.
1915 Fish.Ass.,Tokyo, 1(1):1-24

_____, Contributions to the comparative study of the so-called
1923 scombroid fishes. J.Coll.Agric.Tokyo, 8(3):293-475

go-Leccia, F., The comparative osteology of the scombroid fishes of the
1958 genus *Scomberomorus* from Florida. Bull.Mar.Sci.Gulf Caribb., 8(4):299-341

nacop, P.R., A preliminary systematic study of the Philippine chub
1958 mackerels, family Scombridae, genera *Pneumatophorus* and *Rastrelliger*. Philipp.J.Fish., 4(2):79-100

tsumoto, W.M., Notes on the Hawaiian frigate mackerels of the genus
1960 *Auxis*. Pacif.Sci., 14(2):173-77

nro, I.S.R., Revision of Australian species of *Scomberomorus*. Mem.
1943 Queensland Mus., 12(2):65-95

_____, The rare gempylid fish, *Lepidocybium flavobrunneum*
1949 (Smith). Proc.roy.Soc.Queensland, 60(3):31-41

gan, C.T., On the anatomy and classification of the scombroid fishes.
1909 Ann.Mag.Nat.Hist., (8)3:65-75

ivas, L., A preliminary review of the western North Atlantic fishes of
1951 the family Scombridae. Bull.Mar.Sci.Gulf Caribb., 1(3): 209-30

_____, A review of the tuna fishes of the subgenera *Parathunnus*
1961 and *Neothunnus* (genus *Thunnus*). Ann.Mus.Stor.nat.Genoa, (72):126-48

oyce, W.F., A morphometric study of yellowfin tuna *Thunnus albacares*
1961 (Bonnaterre). MS presented at the Pacific Tuna Biology Conference, Honolulu, Hawaii, Aug.1961. Paper III-6, 79 p. Abstract in: Spec.sci.Rep.U.S.Fish.Wildl.Serv.Fish, 1962 (415):35

Serventy, D.L., 1942 The tuna *Kishinoella tonggol* (Bleeker) in Australia. J.Coun.sci.industr.Res.Aust., 15(2):101-12

_____, 1948 *Allothunnus fallai*, a new genus and species of tuna from New Zealand. Rec.Canterbury Mus., 5(3):131-5

_____, 1956a The southern bluefin tuna, *Thunnus thynnus maccoyii* (Castelnau), in Australian waters. Aust.J.Mar.Freshw.Res., 7:1-43

_____, 1956b Additional observations on the biology of the northern bluefin tuna, *Kishinoella tonggol* (Bleeker), in Australia, Aust.J.Mar.Freshw.Res., 7:44-63

Starks, E.C., 1910 The osteology and mutual relationships of the fishes belonging to the family Scombridae. J.Morph., 21(1):77-99

Takahasi, N., 1926 On the Plecostei, an order of the Teleostomi, established by Prof. Kishinouye. J.Coll.Agric.Tokyo, 7(4):83-98

Talbot, F.H., 1960 Additions to the South African Museum collections of marine fishes. Ann.S.Afr.Mus., 14(2):257-9

Talbot, F.H. and M.J. Penrith, 1926a Tunnies and marlins of South Africa. Nature,Lond., 193:558-9

* _____, 1962b Synopsis of biological data on species of the genus *Thunnus (sensu lato)* (South Africa). Species Synopsis No.19

Talbot, F.H., (in press) South African tunas in the light of recent investigations. MS presented at the Symposium on Scombroid Fishes, Mandapar Camp, India, January, 1962. Abstract in: Symposium on Scombroid Fishes, Abstracts of Papers, The Marine Biological Association of India, 1962.

Wade, C.B., 1949 Notes on the Philippine frigate mackerels, family Thunnidae, genus *Auxis*. Fish Bull.,U.S., No.51, 46:229-40

* Papers presented to the Meeting

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Preliminary Field Guide to the MACKEREL- AND TUNA-LIKE FISHES OF THE INDIAN OCEAN (SCOMBRIDAE)

Bruce B. Collette
Robert H. Gibbs, Jr.

Smithsonian Institution
WASHINGTON
1963

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UNITED STATES NATIONAL MUSEUM
Smithsonian Institution
WASHINGTON, D. C.

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INTRODUCTION

This preliminary guide is intended as an aid for participants in the International Indian Ocean Expedition. Based primarily on the literature, but with some original information from revisionary studies in progress by the writers, it has been prepared to facilitate the field identification of Indian Ocean scombrids, so that critical material for systematic studies can be recognized and saved.

A number of difficulties hinder solution of the taxonomic problems that exist in the Scombridae. Many of the species have widespread distributions; as a result workers have not been able to examine material from all parts of the world, and the lack of Indian Ocean material has been particularly serious. Relatively few specimens, especially of the larger species, have been available for study. Identification of species is often difficult because considerable changes in morphology take place during growth, and because external characters are not always reliable. There are, however, excellent internal characters.

For most species of Indian Ocean scombrids, specimens of various sizes should be saved, some frozen and some preserved, from different parts of the range. In particular, frozen specimens are needed to study the details of the viscera, skeleton, and circulatory system. In this guide, we have listed at the end of the synoptic account of each species the material that seems to be necessary for adequate studies.

Collecting and Preserving

Larger scombrids will be most often taken by Japanese long-line, but will also be caught by trolling lines from ships that are underway. From research vessels, smaller species of scombrids such as Scomber and Rastrelliger, normally taken by commercial methods, will seldom be caught by any method except shallow midwater trawling or, occasionally, by hook and line.

Specimens small enough to fit in available containers may be preserved in a 10 percent formalin solution. (Formalin, containing 40 percent formaldehyde, is mixed at the ratio of 1 part formalin to 9 parts water to obtain this solution.) To insure proper preservation of the internal organs of larger specimens, it is also necessary either to make a slit into the body cavity on the right side, or to inject some of the formalin solution directly into the cavity with a large hypodermic syringe. (In large specimens it is necessary also to inject the muscles of the back in several places.) Do not remove the specimen from the formalin solution for at least two or three days.

When deep-freeze facilities are available, both large and small specimens may be frozen without the treatment described above. The sooner the specimen is frozen, the more useful it will be.

For all persons making shipments of specimens to the United States, the following directions should be followed as closely as possible. For participants in the U. S. Program in Biology of the International Indian Ocean Expedition, procedures have been set up for shipping material, and these procedures can be clarified by consultation with the chief scientist of the expedition or with designated liaison personnel ashore.

WARNING: Unless shipments are sent prepaid, the recipient should be notified well in advance of the sender's intention to send the material so that the institution can arrange to pay the shipping costs.

Preserved specimens. Specimens preserved in formalin should be wrapped either individually or in groups collected at a single time and place. For this purpose cheesecloth, burlap, or other cloth may be used. Be sure the specimens are properly labeled (see Collecting and Preserving). Tie each bundle with string. If plastic bags are available, soak the wrapped specimens in formalin, place them in the bags, press out excess air, and seal the bags by heat or tie them securely closed. No excess formalin need be added if the cloth is thoroughly soaked.

Place specimens in a container for shipping. Except for specimens in plastic bags, special care must be taken that the container is waterproof. Metal cans or tight wooden barrels are satisfactory. Surround the specimens with cotton, excelsior,

newspaper, or other material to prevent abrasion. Do not use sawdust or leaves as packing if the specimens are not protected by waterproof bags, as these materials may stain the specimens. Place the address of the recipient on the inside as well as outside the container, and close securely so that no leakage or evaporation is likely.

Send by ocean freight. For specimens sent to the U. S. National Museum, see addressing procedure on page 6.

Frozen specimens. Frozen specimens must not be allowed to thaw. Prior to shipping, wrap each specimen in aluminum foil, newspaper, or cloth to provide insulation and prevent abrasion. Be sure the specimens are properly labeled. Place the specimens in a wooden box that is insulated as well as possible with excelsior, newspaper, sawdust, or other packing material. If the box is to be removed from the freezer for any length of time, add dry ice to keep the specimens frozen. Place the address of the recipient on the inside as well as outside the box, and close the box securely.

For specimens to be sent to the U. S. National Museum, see addressing procedure on page 6.

Most frozen specimens should be sent by ocean freight. Arrangements must be made in advance with a steamship company that has deep freeze facilities. The shipment must not be delivered to the dock until immediately before the ship is loaded.

In special cases, frozen specimens may be sent by air freight, but this is extremely expensive. During transit, such a shipment must be kept frozen with dry ice. Request the airline to notify the recipient prior to arrival of the shipment. If much time elapses between sending and delivery, the airline may be requested to re-ice the shipment enroute. For this, an extra charge is made.

Addressing Shipments to the Smithsonian Institution

If shipments are sent from outside the boundaries of the United States to the Smithsonian Institution's U. S. National Museum, the containers should be labeled in one of the following ways:

For air freight:

Either:

Smithsonian Institution
U. S. National Museum
Division of Fishes
Washington 25, D. C.
U.S.A.

or:

Ichthyological Laboratory
Bureau of Commercial Fisheries
U. S. National Museum
Washington 25, D. C.
U.S.A.

For ocean freight:

Either:

U. S. Despatch Agent
U. S. Customs Building
South Gay & Lombard Sts.
Baltimore 2, Maryland, U.S.A.

For Smithsonian Institution
U. S. National Museum
Division of Fishes

or:

U. S. Despatch Agent
U. S. Customs Building
South Gay & Lombard Sts.
Baltimore 2, Maryland, U.S.A.

For Ichthyological Laboratory
Bureau of Commercial Fisheries
U. S. National Museum

Adipose eyelid. A translucent membrane covering the front and rear portions of the eye. See Plate 1.

Base. Refers to the dorsal and anal fins. The distance from the point where the front of the anteriormost ray or spine meets the body, to the point where the rear of the posteriormost ray or spine meets the body. See Plate 1.

Caudal keels. Flattened lateral protuberances found near the end of the narrow caudal peduncle. Gasterochisma, Scomber, and Rastrelliger have two fairly small keels on each side extending onto the caudal base. The other scombrid genera also have a large midlateral keel slightly farther forward on the caudal peduncle. See Plate 1. In the more advanced genera the midlateral keel is supported internally by a bony keel which is part of the vertebrae.

Compressed. Laterally flattened. May refer either to teeth or to the body.

Conical. Rounded in cross-section and tapering nearly or quite to a point. Refers to teeth.

Corselet. An area on the anterior part of the body where the scales are usually larger and heavier, contrasting with the posterior part of the body, where the scales are smaller or absent. See Plate 1.

Depth. Refers here to the greatest straight-line distance between the dorsal and ventral surfaces of the body perpendicular to the body axis. Same as body depth.

Dorsal spines. The elements of the first dorsal fin that can be folded back to fit completely into a groove. The last few small spines are often hidden in this groove and must be carefully sought.

Finlets. The small, free, flag-like elements found behind the second dorsal and anal fins. It is often difficult to determine whether the first finlet is actually free or joined to the fin. See Plate 1.

Fork length. The distance from the tip of the snout to the end of the shortest median caudal rays. Measured in a straight line, not over the curvature of the fish. See Plate 1.

Gill filaments. The posteriorly-directed parts of the gills.

Gill rakers. The anteriorly-directed parts of the gills. These are usually comb-like, but in Gasterochisma are patches of spines. They are counted on the first (anterior) gill arch. All elements that protrude above the gill arch are counted. It is frequently necessary to cut out the gill arch if counting is difficult with the arch intact.

Head length. The straight-line distance from the snout tip to the posteriormost part of the operculum. See Plate 1.

Interpelvic process. A more-or-less scale-like process located mid-ventrally between the pelvic fins. It may be small and single (as in Scomber and Rastrelliger), small and double (Scomberomorus), moderately large and double (Euthynnus), or very large and single (Auxis). See Plate 2.

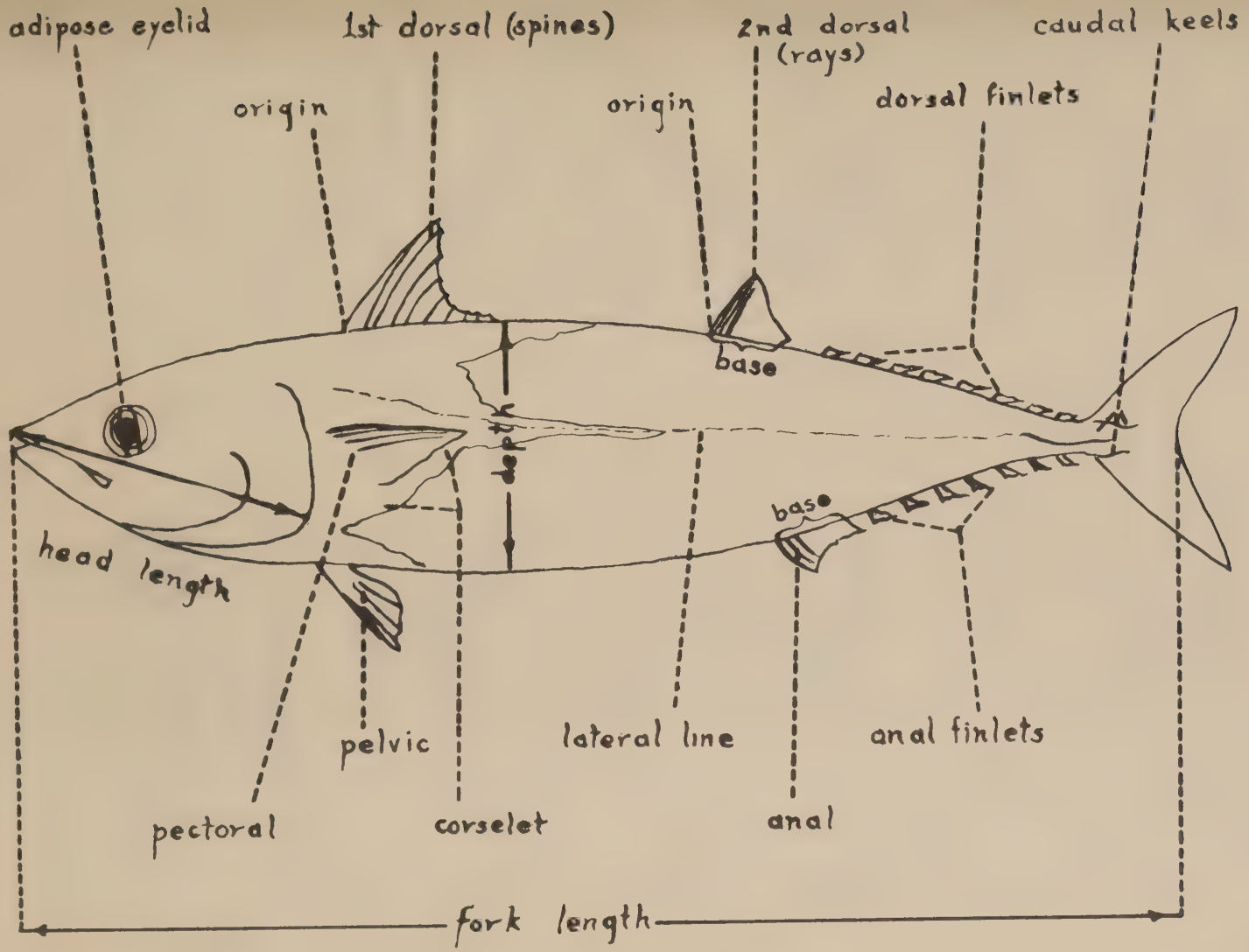
adipose eyelid
1st dorsal (spines)
2nd dorsal (rays)
caudal keels
origin
origin
dorsal finlets
base
base
head length
pelvic
lateral line
anal finlets
pectoral
corselet
anal
fork length

Plate 1

Plate 2. Interpelvic processes

Scomberomorus

Grammatorcynus

Euthynnus
Katsuwonus

Scomber
Rastrelliger

Thunnus

Auxis

Lateral line. Usually one row (two rows in Grammatorcynus) of pore-bearing scales along each side of the body. Not to be confused with other lines caused by pigment or blood vessels.

Origin. The anteriormost part of the dorsal or anal fin, where the first ray or spine meets the body.

Palatines. A pair of bones, one located on each side of the upper jaw inside the jaw bones proper (premaxilla and maxilla). May or may not bear teeth.

Pectoral fins. Paired fins, one on each side of the body, located just behind the gill cover.

Pectoral fin length. The straight-line distance from the anteriormost point where the fin meets the body to the tip of the fin.

Pelvic fins. Paired fins, in scombrid fishes located close together on each side of the midventral line and below the pectoral fins.

Liver. An internal organ that, at its anterior end, abuts against the front end of the body cavity. It may be restricted to the anterior end of the body cavity, or it may have lobes extending far posteriorly. The liver shape is a useful character in some forms. See Plate 3.

Liver striations. More-or-less parallel dark lines on the ventral surface of the liver, due to the arrangement of blood vessels. Found only in Thunnus alalunga, T. obesus, and T. thynnus. See Plate 3.

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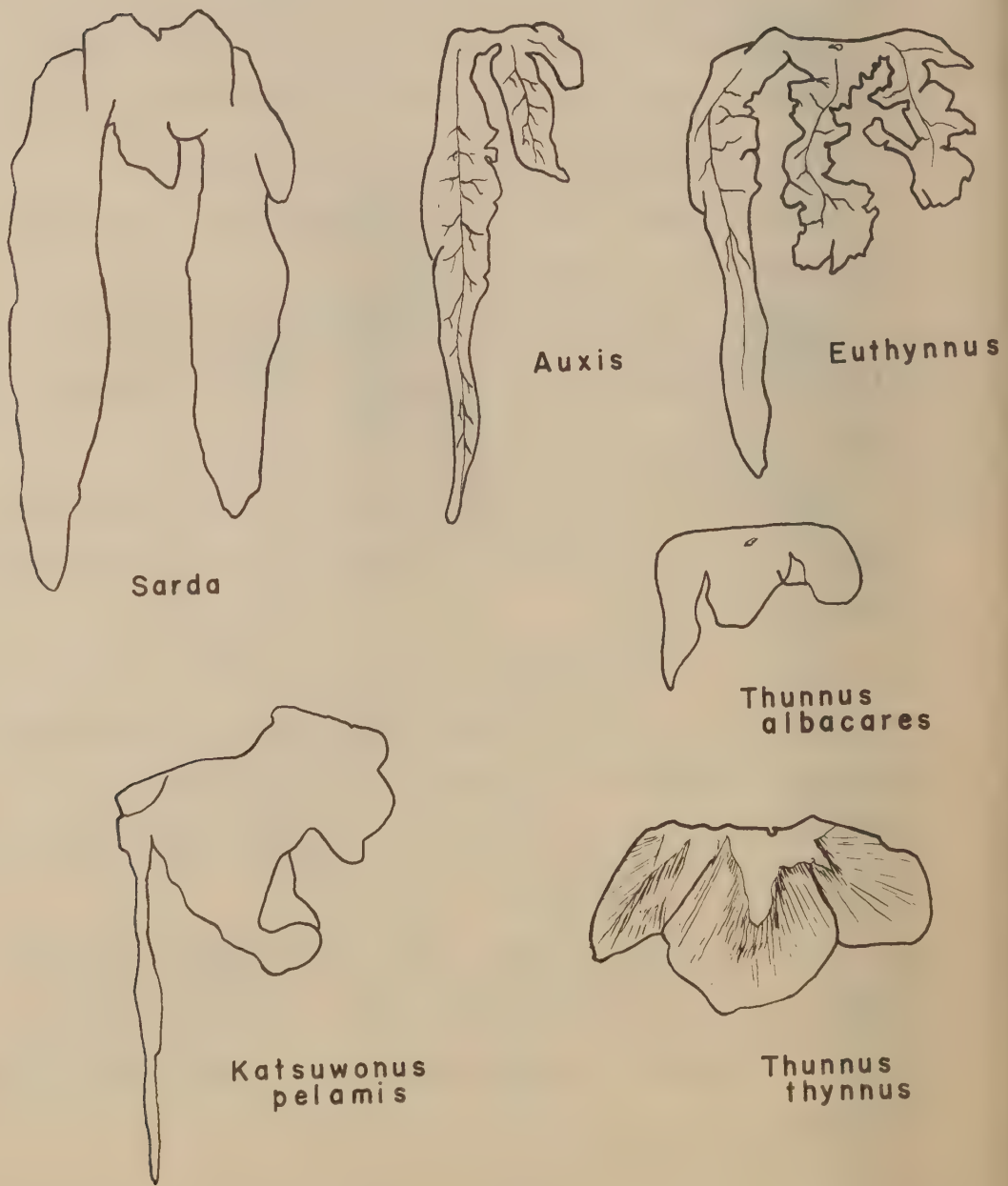
Vomer. A single median bone located in the upper anterior part of the mouth behind the jaw bone (premaxilla). May or may not bear teeth.

Plate 3. Representative livers



KEY TO THE GENERA AND SPECIES

OF SCOMBRIDAE KNOWN

FROM THE INDIAN OCEAN

1a. Long deep groove present along abdomen from pelvic base to anus into which the large pelvic fins fit. (Plate 4) . . . . . Gasterochisma melampus

1b. No long abdominal groove 2

2a. Entire body covered with moderately large scales; gill-rakers very long, longer than gill filaments, plainly visible through open mouth. (Plate 5) . . . . Rastrelliger

2b. Scales, if present, minute and difficult to discern at least on posterior portion of body; gill-rakers not as long as gill filaments, hardly or not at all visible through open mouth 3

3a. First and second dorsal fins separated by a distance equal to or greater snout length 4

3b. First and second dorsal fins separated by a distance not longer than the eye diameter 6

4a. Body completely covered with small scales; interpelvic process very small, much shorter than the shortest pelvic ray; adipose eyelids covering front and rear of eye; only two small keels present on each side of caudal peduncle; dorsal and anal finlets 5. (Plate 5) . . . . . Scomber

4b. Body covered with scales anteriorly, mostly naked posteriorly; interpelvic process about as long as pelvic fins; no adipose eyelids; in addition to two small keels, a large mid-lateral keel present on each side of caudal peduncle; dorsal finlets 8, anal finlets 7 . . . . . Auxis 5

5a. Corselet of scales along lateral line 1-5 scales wide under second dorsal fin; dark wavy lines in dorsal scaleless area usually oblique to nearly horizontal; pectoral fin extending posterior to a vertical from anterior margin of dorsal scaleless area. (Plate 8) . . . . . Auxis thazard

5b. Corselet of scales more than 6 scales wide under second dorsal fin; dark bars in the dorsal scaleless area usually nearly vertical; pectoral fin not reaching a vertical from anterior margin of dorsal scaleless area. (Plate 8) . . . . . Auxis rochei

6a. Lateral line with a dorsal and ventral branch; interpelvic process single. (Plate 7) . . .Grammatorcynus bicarinatus

6b. A single main lateral line, sometimes with short side branches; interpelvic process double 7

7a. No corselet present, body entirely covered with scales of rather uniform size 8

7b. A corselet present, consisting of an anterior thickened area of larger, modified scales, the posterior scales smaller or absent 13

8a. Dorsal spines 21-27; snout as long as rest of head; gill-rakers absent. (Plate 7) . . . . . *Acanthocybium solanderi*

8b. Dorsal spines 14-17; snout much shorter than rest of head; gill-rakers present (although sometime reduced to 1 plus 2) . . . . . .*Scomberomorus* 9

9a. Sides marked with spots or horizontal lines; lateral line forming an even or wavy curve from head to tail, not abruptly bent downward in region below end of second dorsal fin 10

9b. Sides with numerous wavy vertical bands; lateral line abruptly bent downward below end of second dorsal fin. (Plate 6). . . . . *Scomberomorus commersoni*

10a. Body marked with irregular dark horizontal lines as well as some spots. (Plate 6) . . *Scomberomorus lineolatus*

10b. Body marked only with spots 11

11a. Spots on body smaller than eye; gill-rakers moderately long, 10-14 on first arch 12

11b. Spots on body larger than eye; gill-rakers short, 8 or fewer on first arch. (Plate 6) . . . . . *Scomberomorus queenslandicus*

12a. An area of ramifying canals along both sides of lateral line . . . . . *Scomberomorus kuhlii*

12b. No area of ramifying canals along lateral line . . . . . *Scomberomorus guttatus*

13a. Tongue with a pair of dorsally-projecting longitudinal cartilaginous ridges 17

13b. Tongue without dorsally-projecting ridges 14

14a. Jaw teeth very small; gill-rakers 71-77 on first arch. (Plate 9) . . . . . Allothunnus fallai

14b. Jaw teeth large and prominent; gill-rakers 11-14 on first arch 15

15a. Five to ten narrow, dark longitudinal stripes on upper part of body; no teeth on tongue; dorsal spines 17-18. (Plate 9) . . . . . Sarda orientalis

15b. Body either without stripes or with dark spots above lateral line, longitudinal dark stripes below; teeth present on tongue; dorsal spines 14-16 16

16a. Body with dark spots above lateral line, dark longitudinal stripes below; first dorsal fin very high anteriorly, higher than second dorsal. (Plate 7) . . . . . Cybiosarda elegans

16b. Body without dark spots or stripes; first dorsal fin lower than second dorsal. (Plate 7) . . . . . Gymnosarda unicolor

17a. Three to five prominent dark longitudinal stripes on lower part of body; gill-rakers 53-63 on first arch; dorsal spines 15-16; no teeth on palatines or vomer. (Plate 9) . . . . . Katsuwonus pelamis

17b. No dark longitudinal stripes on lower part of body; gill-rakers 19-43 on first arch; dorsal spines 11-14; teeth present on palatines and vomer 18

18a. Body naked except for corselet and lateral line; several black spots usually present between pectoral and pelvic fins; pectoral rays 26-27. (Plate 9) . . . . . Euthynnus affinis

18b. Body covered with small scales behind corselet; no black spots present between pectoral and pelvic fins; pectoral rays 30-36. (see Synopsis as well as Key for all species) . . . . . Thunnus 19

19a. Caudal fin with a narrow white posterior margin; body deepest posterior to mid-length, at or slightly before level of second dorsal fin; pectoral fin very long, reaching well past end of second dorsal fin base (similar in smaller T. obesus); liver striated on ventral surface. (Plate 10) . . . . . Thunnus alalunga

19b. Caudal fin without white posterior margin; body deepest at about mid-length, near middle of first dorsal fin; pectoral fin short to moderately long, not reaching end of second dorsal base (except in smaller T. obesus) 20

20a. Total gill-rakers on first arch 19-26 (mean about 22); lower sides with pattern of pale streaks and spots either horizontally oriented or without obvious orientation; liver without striations on ventral surface. (Plate 10) . . . . . .*Thunnus tonggol*

20b. Total gill-rakers on first arch 23 or more; lower sides either lacking pale streaks and spots, or with such markings at least partly in vertical rows 21

21a. Pectoral fin short, less than 80% of head length; gill-rakers on first arch 31-43; liver striated on ventral surface. (Plate 10) . . . . . *Thunnus thynnus*

21b. Pectoral fin longer, greater than 80% of head length; gill-rakers on first arch 23-34 22

22a. Liver striated on ventral surface; second dorsal and anal fins not elongated, equal to 20% of fork length or less at all sizes. (Plate 10) . . . . . *Thunnus obesus*

22b. Liver without striations on ventral surface; second dorsal and anal fins of larger specimens (120 cm fork length or more) elongated, greater than 20% of fork length. (Plate 10) . . . . . *Thunnus albacares*

Gasterochisma melampus Richardson

Plate 4

Distinguishing characteristics: This species looks unlike any other scombrid partly because of its large, tarpon-like scales and blunt dolphin-like head. The pelvic fins are very large in smaller individuals, as long as the abdominal groove, which reaches to the anus. In larger specimens, the fins are relatively shorter, occupying only about a third of the abdominal groove.

Size: The largest specimen on record was 165 cm (65 inches) total length.

Known range: Very few specimens have come to the attention of biologists. These specimens have come from Argentina, Cape of Good Hope, the southern Indian Ocean, Australia, and New Zealand.

Study material needed: This species is so poorly known that all specimens should be saved, frozen or preserved, regardless of size. Because the species is so distinctive, skeletal material should also be saved if the whole fish cannot be retained.

Genus Scomber

Mackerels

Plate 5

Generic characteristics: Scomber is similar to Rastrelliger and different from most other scombrids in having an adipose eyelid, a poorly developed corselet, a single small interpelvic process, and only two small keels on each side of the caudal peduncle. Scomber has smaller scales, fewer and shorter gill-rakers, is more elongate, and the body is more rounded in cross section than Rastrelliger.

Species: The number of species of mackerels is uncertain, and a great deal of study will be necessary before this can be decided. There appear to be two species in the Indian Ocean, S. japonicus Houttuyn, which is cosmopolitan, and S. australasicus Cuvier, with uncertain distribution, but known at least from the Philippines.

Specific characteristics: The following characteristics have been used to distinguish S. japonicus from S. australasicus by Manacop (1958).

1a. Greatest body depth goes 4.07 to 4.14 times into standard length; 4.56 to 4.82 times into total length; lateral line scales about 155; body somewhat compressed. Anal spine very feeble and attached to fin . . . . Scomber australasicus

1b. Greatest body depth goes 5.25 to 5.52 times into standard length; 5.94 to 6.40 times into total length; lateral line scales about 180; body more or less rounded. Anal spine short but strong and free from fin . . . . . Scomber japonicus

Study material needed: Series of 10 to 20 preserved specimens of both species are needed from as many parts of the range as possible.

Genus Rastrelliger

Plate 5

Generic characteristics: Similar to Scomber in a number of characters and differing primarily in having large prominent scales, many long feather-like gill-rakers which are plainly visible when the mouth is opened, and a deeper more compressed body.

Species: Like Scomber, the genus Rastrelliger is badly in need of revision. Most workers have recognized two species, both found throughout the central tropical Indo-Pacific. R. brachysoma (Bleeker) is a very deep-bodied species (depth of body less than 3.5 times in length) and R. kanagurta (Cuvier) sometimes known as R. chrysozona (Peters), is a more slender-bodied species (body depth more than 3.5 times in length). The number of gill-rakers has also been used to distinguish the species, but different workers are not in agreement as to the number of rakers.

Study material needed: Series of 10-20 preserved specimens from many localities are needed to revise this genus.

Genus Scomberomorus

Plate 6

Generic characteristics: Species of this genus are relatively elongate and compressed. The teeth in the jaws are strong and compressed, similar to those in Grammatorcynus and Acanthocybium. The body is completely scaled, and there appears to be no anterior corselet of modified scales. The interpelvic process is paired and very small. Gill-rakers are present, but may be reduced in number to as few as three or four.

The species have not been studied on a worldwide basis. Recent estimates of the number of species range from nine to fifteen. At least four, perhaps five or more species may occur in the Indian Ocean. Both frozen and preserved specimens of all species should be saved whenever possible.

Scomberomorus lineolatus (Cuvier)

Kanadi or Bowrega

Plate 6

Distinguishing characteristics: Upper part of body marked with a series of irregular, horizontal, narrow black lines, breaking up into spots ventrally. Gill-rakers on upper limb of first arch 2-3, on lower limb 8-12.

Maximum known size: Reported to reach a length of 90 cm (about 36 inches) and a weight of about 5.5 kg (12 pounds).

Known range: East African coast; India, Ceylon, East Indies.

Study material needed: Several specimens, frozen and preserved, from representative parts of the range. Eastern and western Indian Ocean forms may be different species. Special effort should be made to collect specimens from the eastern part of the Indian Ocean.

Scomberomorus queenslandicus Munro

Queensland School Mackerel

Plate 6

Distinguishing characteristics: This species has the sides marked with round spots that are larger than the eye. In the other spotted forms, S. guttatus and S. kuhlii, the spots are more numerous and are smaller than the eye. The gill-rakers are short and number 0-1 on the upper limb, 4-7 on the lower limb of the first arch.

Maximum known size: The average size of specimens caught is about 50 cm (19 inches) and 1-2 kg (3-4 pounds). Fish of 75 cm (30 inches) have been taken.

Known range: East and west coasts of Australia between 10° and 30°S.

Study material needed: Because the species is known at present only from Australia, any material from the Indian Ocean, frozen or preserved, would be of interest.

Scomberomorus guttatus (Bloch and Schneider)

and S. kuhlii (Cuvier)

Plate 6

Distinguishing characteristics: Both of these species are marked with small round spots. The distinction between them is uncertain. S. kuhlii is said to have an area of ramifying canals along both sides of the lateral line, while S. guttatus lacks this development. This character needs to be checked carefully. The number of gill-rakers in Indian specimens identified as S. guttatus is recorded as 1-3 on the upper limb, 7-10 on the lower limb of the first arch.

Maximum known size: Commonly 45-52 cm (18-20 inches) long, 0.5-1.5 kg (1-3.5 pounds). It is known to reach 81.5 cm (32 inches).

Known range: The type locality of S. guttatus is Tranquebar, India; that of S. kuhlii is Java. Their combined ranges may be given as from southeast Africa and Madagascar through the Iranian Gulf, India, and the Indo-Malayan Archipelago, to the Philippines, China, Formosa, and Japan.

Study material needed: Several frozen or preserved specimens from representative parts of the range.

Scomberomorus commersoni (Lacépède)

Narrow-barred Spanish Mackerel

Plate 6

Distinguishing characteristics: Gill-rakers greatly reduced in both size and number: 0-2 on the upper limb, 2-6 on the lower limb of the first arch. Lower part of body marked with numerous vertical wavy bars. The lateral line bends downward abruptly below the end of the second dorsal fin.

Maximum known size: This species is the largest in the genus. The world record for hook and line is a fish 170 cm (67 inches) long, weighing 29 kg (64 pounds) from Mozambique. Possibly attains a weight of 54 kg (120 pounds).

Known range: Believed to occur at least seasonally from eastern Africa and the Red Sea, throughout Indo-Australian waters, to China and Japan.

Study material needed: Representative specimens, frozen and preserved, throughout the size range, from various parts of the geographic range. Mauritius is the type locality; specimens from this island are particularly desired.

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Acanthocybium solanderi (Cuvier)

Wahoo

Plate 7

Distinguishing characteristics: This is an elongate species somewhat resembling the species of Scomberomorus. It has a tubular, beak-like snout, has no gill-rakers, and has more dorsal spines (21-27) than any other scombrid.

Maximum known size: The world record for hook and line is 206 cm (81 inches), 63 kg (139 pounds).

Known range: Apparently found in all tropical and subtropical seas, mainly in offshore waters.

Study material needed: A few specimens, frozen or preserved, from various parts of the range.

Grammatorcynus bicarinatus (Quoy and Gaimard)

Double-lined Mackerel

Plate 7

Distinguishing characteristics: This is the only species of scombrid that has two distinct lateral lines. The upper one begins at the opercle and runs along the dorsal half of the body almost to the caudal keel. The lower lateral line branches from the upper one below the first dorsal fin, descends sharply and runs posteriorly to join the upper lateral line. Teeth are present on the vomer, palatines, and tongue. Total gill-rakers on first arch 19-21. Unlike Scomberomorus, Grammatorcynus has a single interpelvic process (see Plate 2).

Maximum known size: The largest known specimen is 96 cm (about 38 inches).

Known range: This species is known from the Andaman Sea eastward through the coastal and insular waters of the Indo-Malayan Archipelago, Australia, and the Philippine, Ryu-Kyu, and Marshall Islands. It has also been reported from the Red Sea but there appear to be no records between there and the Andaman Sea.

Study material needed: Several frozen specimens are desired, and a few specimens should be preserved from various parts of the range. Material from the Indian Ocean west of the Andaman Sea would be especially valuable.

Cybiosarda elegans (Whitley)

Leaping Bonito

Plate 7

Distinguishing characteristics: This is the only species of scombrid with dark spots above the lateral line and longitudinal dark stripes below. It is somewhat similar in body proportions to Sarda, but has teeth on the tongue, a much higher first dorsal fin and spots rather than stripes above the lateral line; Cybiosarda has 15-16 dorsal spines, Sarda 17-18. The stripes below the lateral line suggest Katsuwonus pelamis, but Katsuwonus lacks spots above the lateral line and has many more gill-rakers (53-63 vs. 14 or fewer).

Maximum known size: This species reaches 41 cm (16 inches) and 0.9 kg (2 pounds).

Known range: Coasts of eastern and western Australia between about 20-35°S.

Study material needed: The relationship of this form to other scombrids is confused. Numerous specimens are needed, both frozen for anatomical studies, and preserved. Photographs would also be valuable, if accompanied by locality, date, and some indication of size.

Gymnosarda unicolor (Rüppell)

Dogtooth Tuna

Plate 7

Distinguishing characteristics: The teeth of this species are larger than those of most other scombrids. Grammatorcynus, Scomberomorus and Acanthocybium have large teeth, but they are laterally compressed, while those of Gymnosarda are conical. Sarda also has large, conical teeth, but has dark stripes on the upper half of the body, which are lacking in Gymnosarda. This is the only genus of scombrids known to have two distinct patches of villiform teeth on the tongue.

Maximum known size: Reliable reports indicate that G. unicolor reaches 150 cm (59 inches) and 30 kg (about 66 pounds), although the species may attain even larger sizes.

Known range: Red Sea; Laccadives eastward to Japan, eastern Australia, and the Marshall Islands.

Study material needed: Several specimens, frozen or preserved, from various parts of the range.

Sarda orientalis (Temminck and Schlegel)

Oriental Bonito

Plate 9

Distinguishing characteristics: This species has five to ten narrow longitudinal dark stripes on the upper part of the body. An anterior corselet of modified scales is present; the remainder of the body is covered with minute scales. There are no dorsally-projecting longitudinal cartilaginous ridges and no teeth on the tongue. Dorsal spines 17-18.

Maximum known size: This species reaches roughly 81 cm (32 inches) and 3 kg (7 pounds).

Known range: Throughout the Indian and Pacific Oceans, mostly in tropical and subtropical waters.

Study material needed: Several frozen or preserved specimens from representative parts of the range.

Allothunnus fallai Serventy

Plate 9

Distinguishing characteristics: This distinctive species has a corselet and very small teeth. It has more gill-rakers on the first arch (71-77) than any other scombrid.

Maximum known size: The longest recorded specimen was 96.5 cm (38 inches) in fork length, 6.8 kg (15 pounds). A 13.6 kg (30-pound) specimen has been reported, but no length was given.

Known range: Auckland Islands, New Zealand, Tasmania, South Africa, all in high southern latitudes.

Study material needed: Very few specimens have ever been taken. All material should be saved, either frozen or preserved.

Genus *Auxis*

Frigate Mackerels

Plate 8

Generic characteristics: Similar to *Scomber* and *Rastrelliger* in having the two dorsal fins separated by a wide space. Differs from both genera in having usually 8 dorsal and 7 anal finlets; *Scomber* has 5 of each, *Rastrelliger* 5 or 6 of each. *Auxis* has a scaly corselet anteriorly and is naked posteriorly. Both *Scomber* and *Rastrelliger* are entirely covered with scales and lack a corselet. In *Auxis* the interpelvic process is single and is larger than in any other scombrid, being as long as the pelvic fins.

Species: Workers have generally recognized two species of *Auxis* throughout the Indo-Pacific for which the names *A. thazard* (Lacépède) and *A. rochei* (Risso) appear applicable. In both species an extension of the corselet follows the lateral line posteriorly. *A. thazard* is the "narrow-corseleted form", in which the extension is 1-5 scales wide below the second dorsal fin. In *A. rochei*, the "wide-corseleted form", the extension is six or more scales wide below the second dorsal. These scales are difficult to count, so that magnification should be used, particularly in specimens suspected of being *A. thazard*.

In the Indian Ocean, the number of gill-rakers seem to be a good distinguishing character. *A. thazard* is reported to have

a total of 37-43 rakers (mean about 40); A. rochei has 40-47 (mean about 45).

Other, more uncertain, characters have also been used. The scaleless area above the corselet extends well anterior to the tip of the pectoral fin in A. thazard, but in A. rochei extends only slightly, if at all, anterior to the pectoral tip. The color pattern in the scaleless area above the corselet consists of oblique to nearly horizontal dark wavy lines in A. thazard; in A. rochei there are broad, nearly vertical dark bars in this area. A. thazard has a deeper body that appears laterally more compressed than that of A. rochei, which may appear almost circular in cross section. This character is difficult to utilize by untrained observers.

Maximum known size: A. rochei is said to attain a length of 60 cm (almost two feet) and A. thazard reaches at least 42 cm (16.5 inches).

Known range: Both species are widely distributed in tropical and subtropical waters of the Indo-Pacific and probably the Atlantic. In the Indian Ocean A. rochei is found north of 40°S in inshore waters and near islands.

Study material needed: Series of specimens of both species, frozen or preserved, from various parts of the range should be saved. Probably trolling with a small hook is the best method for catching these forms.

Euthynnus affinis (Cantor)

Black Skipjack

Plate 9

Distinguishing characteristics: This species has a scaly anterior corselet, behind which the body is naked. It differs from the species of Auxis in having the dorsal fins only narrowly separated. From Katsuwonus pelamis it differs in having narrow stripes above the lateral line instead of wide stripes on the lower part of the body, in having about 29-34 gill-rakers rather than 53-63, and in having 14 or fewer dorsal spines rather than 15-16. Allothunnus fallai has many more gill-rakers (71-77) than E. affinis. E. affinis may be distinguished from all other Indian Ocean scombrids having a corselet by the presence of a variable number of dark spots below the pectoral fin; these are very rarely absent. The nominal form E. yaito is now included as a synonym of E. affinis.

Maximum known size: This species reaches a length of about one meter (39 inches) and a weight of 10 kg (22 pounds) or more.

Known range: Tropical and subtropical Indo-Pacific.

Study material needed: Several specimens, frozen and preserved from various parts of the range.

Katsuwonus pelamis (Linnaeus)

Oceanic Skipjack

Plate 9

Distinguishing characteristics: The prominent, dark longitudinal stripes below the lateral line distinguish K. pelamis from all Indian Ocean scombrids except Cybiosarda elegans. Cybiosarda has dark spots above the lateral line which are lacking in Katsuwonus, and has only 13 or 14 gill-rakers, compared to 53-63 in Katsuwonus.

Maximum known size: The species reaches about a meter (39 inches) in length and 18 kg (40 pounds) in weight. It is said to rarely attain 22.5 kg (50 pounds).

Known range: Cosmopolitan in tropical and subtropical seas.

Study material needed: A few specimens, frozen or preserved, from various parts of the range.

Genus *Thunnus*

Tunas

Plate 10

Generic characteristics: The body is fully scaled, with the anterior scales modified to form a corselet. The pectoral rays, 30-36, are more numerous than in any other scombrid. There are no prominent dark stripes, bars, or spots on the body.

Species: Five species occur in the Indian Ocean. Some of these are almost impossible to identify with certainty by external characters alone. For example, the very long pectoral fin of *T. alalunga* would be diagnostic but for the fact that in *T. obesus*, the fin is proportionally as long in smaller specimens, becoming relatively shorter in large specimens. *T. obesus* and *T. albacares* differ mainly in body proportions.

In every possible case, the ventral surface of the liver would be examined for the presence or absence of striations (see Plate 3). This character by itself will distinguish the most confusing species: *T. obesus* from *T. albacares* and *T. tonggol* from *T. thynnus*.

T. alalunga (Bonnaterre)

Albacore

Plate 10

Distinguishing characteristics: The narrow, white caudal fin margin and the dark anal finlets distinguish T. alalunga from all other Indian Ocean tunas. The body shape also differs in being deepest at a more posterior point than in other tunas, at or only slightly before the second dorsal fin, rather than near the middle of the first dorsal fin base. The pectoral fin is very long, reaching posterior to the base of the second dorsal; only smaller T. obesus have pectorals as long. The ventral surface of the liver is striated. Gill-rakers 25-32.

Maximum known size: The hook and line record is 137 cm (54 inches) 31 kg (69 pounds). There is a reliable report of a specimen 128 cm (50 inches) fork length, 42 kg (93 pounds).

Known range: Cosmopolitan in tropical, subtropical, and temperate waters of the world. Its distribution in the Indian Ocean is concentrated between 5°N and 30°S.

Study material needed: A few specimens, frozen or preserved, of various sizes.

T. thynnus (Linnaeus)

Bluefin Tuna

Plate 10

Distinguishing characteristics: The short pectoral fin (less than 80% of head length) distinguishes T. thynnus from all other members of the genus except large T. tonggol, which lacks striations on the ventral surface of the liver and has far fewer gill-rakers (19-25 vs. 31-43).

Populations: On the basis of gill-raker counts and anatomical characters, it appears that there are two or, perhaps, three differentiated populations of T. thynnus, one in the Atlantic, one in the eastern Pacific and one in the Indo-West Pacific. The Atlantic population has the highest average number of gill-rakers (34-43, mean 38.8); the Australian population has the lowest number (31-40, mean 33.7).

From off South Africa specimens quite similar to those from near Australia have been taken in summer (December-February), suggesting either that a single population may be found, at least seasonally, across the breadth of the Indian Ocean, or that there is more than one geographically distinct subpopulation of this form. Other specimens, taken in winter (May-September), appear to belong to the Atlantic population. Thus both populations seem to occur, at different seasons, in this region.

To resolve the many intraspecific problems involved, numerous specimens will be necessary.

Maximum known size: Atlantic specimens attain a weight of more than 454 kg (1000 pounds). Indian and Pacific Ocean forms apparently do not become as large. Japanese fish of 375 kg (825 pounds) have been reported, but specimens weighing more than 136 kg (300 pounds) are relatively unusual.

Known range: Worldwide, mainly in subtropical and temperate waters. There are wide gaps in the known distribution. Within the Indian Ocean, known from areas around Australia and from off South Africa.

Study material needed: Several specimens, frozen and preserved from various parts of the range. Any material taken west of 100°E would be extremely valuable. None have been seen in most of the mid-Indian Ocean. Because specimens are often large and difficult to save and ship, we would like to have the first gill arch preserved from as many individuals as possible, complete with locality, date, and fork length of the fish.

T. obesus (Lowe)

Bigeye Tuna

Plate 10

Distinguishing characteristics: T. obesus must be identified by elimination. T. thynnus has a much shorter pectoral fin (less than 80% of head length). T. tonggol has fewer gill-rakers (19-25 vs. 23-31, with less than 5% 23-25), lacks liver striations, and has horizontally-oriented pale spots and streaks on the lower part of the sides. The pectoral fins of T. obesus are as long as those of T. alalunga in the size range of the latter, but T. alalunga is deepest more posteriorly than T. obesus and differs in some aspects of coloration. The best means of distinguishing T. obesus from T. albacares is by the striations on the ventral surface of the liver, which are lacking in T. albacares. Other comparisons are discussed under that species.

The nominal forms Parathunnus sibi and P. mebachi are now considered to be synonyms of T. obesus.

Maximum known size: The largest known specimen is the hook and line record taken off Peru, 236 cm (93 inches), 198 kg (435 pounds).

Known range: Cosmopolitan in tropical and subtropical seas. In the Indian Ocean found mainly north of 30°S.

Study material needed: Small and medium-sized specimens (up to five feet long), frozen or preserved, are strongly desired. Specimens smaller than 3 feet long would be particulary valuable.

T. albacares (Bonnaterre)

Yellowfin Tuna

Plate 10

Distinguishing characteristics: A combination of internal and external characters must be used to identify this species with certainty. T. alalunga has longer pectoral fins which reach past the second dorsal base, is deepest at or slightly before the second dorsal origin, has a white margin on the tail, and has dark finlets. T. thynnus has a shorter pectoral fin, less than 80% of the head length. T. obesus and T. tonggol are both more difficult to distinguish from T. albacares.

The liver of T. albacares lacks the striations that are present in T. obesus. Large specimens of T. obesus never have the elongated second dorsal and anal fins of large T. albacares. When specimens of similar size are compared, T. obesus is generally heavier, deeper, and has a larger eye.

T. tonggol like T. albacares, lacks striations on the liver, but has fewer gill-rakers (19-26, vs. 25-34 in T. albacares). In both species, the pectoral fins become relatively shorter as the fish becomes longer, but at any given size, the fin is longer in T. albacares. T. tonggol has a pattern of horizontally-oriented pale streaks and spots on the lower part of the sides, whereas smaller T. albacares which have such pale markings have them partly in vertical rows.

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The nominal form Neothunnus macropterus (Temminck and Schlegel) is now considered to be a synonym of T. albacares.

Maximum known size: The largest Indian Ocean specimen on record was 195 cm (77 inches) long. This would weigh about 136 kg (300 pounds). Probably this is close to maximum size, although there are unconfirmed reports of fish weighing 181 kg (400 pounds) or more.

Known range: Cosmopolitan in tropical and subtropical seas. Within the Indian Ocean, most are found north of 30°S.

Study material needed: A few small (less than about two feet long) specimens, frozen or preserved.

T. tonggol (Bleeker)

Longtail or Northern Bluefin Tuna

Plate 10

Distinguishing characteristics: This species has fewer gill-rakers than any other Indian Ocean Thunnus (19-25), although there is slight overlap with T. obesus (23-31). It is the only tuna with pale spots and streaks oriented horizontally on the lower part of the body; smaller individuals of the other species may have pale markings, but they are at least partly oriented vertically. The liver lacks ventral striations, as in T. albacares. The pectoral fin is moderately long in smaller specimens, but becomes relatively shorter in larger ones. The forward position of the second dorsal fin (i.e. length of tail) has been used as a distinguishing character for T. tonggol, but T. albacares overlaps it widely in this respect.

This species has frequently been placed in the nominal genus Kishinoella.

Maximum known size: This is the smallest species of Thunnus in the Indian Ocean. Large fish are about 105 cm (45 inches) long and weigh about 18 kg (40 pounds), while 27 kg (60-pound) fish have been recorded.

Known range: Red Sea; India to the Philippines, Japan, and eastern Australia.

Study material needed: Although this is an important commercial fish, at least in India and Australia, few specimens are available for study. Samples of various sizes, frozen and preserved, from throughout the range are needed.

REFERENCES

FRASER-BRUNNER, A.

1949. On the fishes of the genus Euthynnus. Ann. & Mag. Nat. Hist., ser. 12, vol. 2, pp. 622-627.

1950. The fishes of the family Scombridae. Ann. & Mag. Nat. Hist., ser. 12, vol. 3, pp. 131-163.

GODSIL, H.C.

1954. A descriptive study of certain tuna-like fishes. California Div. Fish & Game, Fish Bull. no. 97, pp. 188. (Scomber, Sarda, Auxis, Euthynnus)

1955. A description of two species of bonito, Sarda orientalis and S. chiliensis and a consideration of relationships within the genus. California Div. Fish & Game, Fish Bull. no. 99, pp. 43.

GODSIL, H. C., and EYERS, ROBERT D.

1944. A systematic study of the Pacific tunas. California Div. Fish & Game, Fish Bull. no. 60, pp. 131. (Katsuwonus, Thunnus)

GODSIL, H. C., and HOLMBERG, EDWIN K.

1950. A comparison of the bluefin tunas, genus Thunnus from New England, Australia and California. California Div. Fish & Game, Fish Bull. no. 77, pp. 55.

JONES, S.

1958. Notes on frigate mackerels, Auxis thazard (Lacépède) and Auxis tapeinosoma Bleeker, from Indian waters. Indian J. Fish., vol. 5, no. 1, pp. 189-194.

JONES, S., and SILAS, E. G.

1960. Indian tunas - a preliminary review, with a key for their identification. Indian J. Fish., vol. 7, no. 2, pp. 369-393.

1962. On fishes of the subfamily Scomberomorinae (family Scombridae) from Indian waters. Indian J. Fish., vol. 8, no. 1, pp. 189-206 (1961).

KISHINOUYE, KAMAKICHI

1923. Contributions to the comparative study of the so-called scombroid fishes. J. Coll. Agric. Imper. Univ. Tokyo, vol. 8, no. 3, pp. 293-475.

MANACOP, PORFIRIO R.

1958. A preliminary systematic study of the Philippine chub mackerels, family Scombridae, genera Pneumatophorus and Rastrelliger. Philippine J. Fish., vol. 4, no. 2, pp. 79-101.

MATSUMOTO, WALTER M.

1960. Notes on the Hawaiian frigate mackerel of the genus Auxis. Pacific Sci., vol. 14, no. 2, pp. 173-177.

MUNRO, IAN S. R.

1943. Revision of Australian species of Scomberomorus. Mem. Queensland Mus., vol. 12, no. 2, pp. 65-95.

RANADE, M. R.

1961. Notes on the tuna and frigate mackerel from Ratnagiri. J. Bombay Nat. Hist. Soc., vol. 58, no. 2, pp. 351-354.

SERVENTY, D. L.

1941. The Australian tunas. Council Sci. & Ind. Res. Pamph. no. 104, pp. 48.

1948. Allothunnus fallai, a new genus and species of tuna from New Zealand. Rec. Canterbury Mus., vol. 5, no. 3, pp. 131-135.

1956a. The southern bluefin tuna, Thunnus thynnus maccoyii (Castelnau), in Australian waters. Australian J. Mar. Freshw. Res., vol. 7, no. 1, pp. 1-43.

1956b. Additional observations on the biology of the northern bluefin tuna, Kishinoella tonggol (Bleeker) in Australia. Australian J. Mar. Freshw. Res., vol. 7, no. 1, pp. 44-63.

TALBOT, FRANK H., and PENRITH, M. J.

1962. Tunnies and marlins of South Africa. Nature, no. 4815, vol. 193, pp. 558-559.

WADE, CHARLES B.

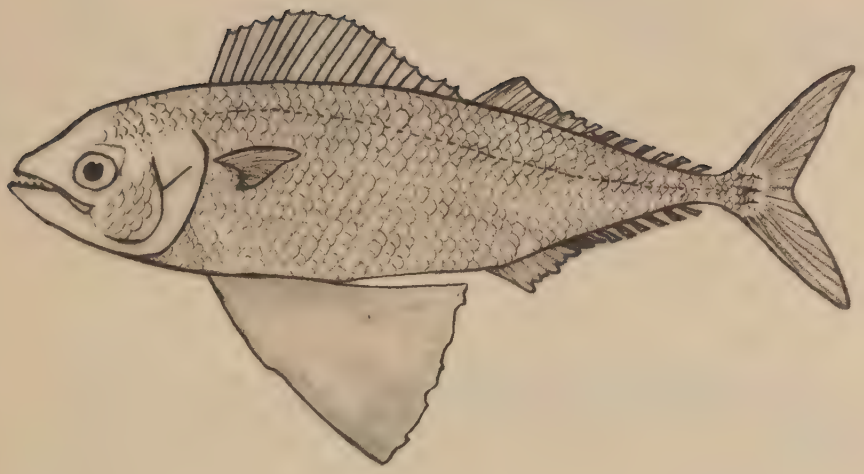
1949. Notes on the Philippine frigate mackerels, family Thunnidae, genus Auxis. U. S. Fish & Wildlife Serv. Fish. Bull. no. 46, vol. 51, pp. 229-240.

WHITLEY, GILBERT P.

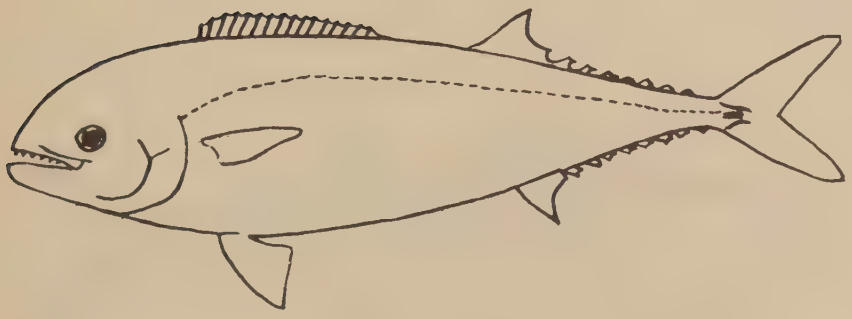
1936. More ichthyological miscellanea. Mem. Queensland Mus., vol. 11, no. 1, pp. 23-51. (Cybiosarda, Scomberomorus)

WILLIAMS, FRANK

1960. On Scomberomorus lineolatus (C.V.) 1831, from British East African waters (Pisces, Scombridae.) Ann. & Mag. Nat. Hist., ser. 13, vol. 3, no. 27, pp. 183-192.

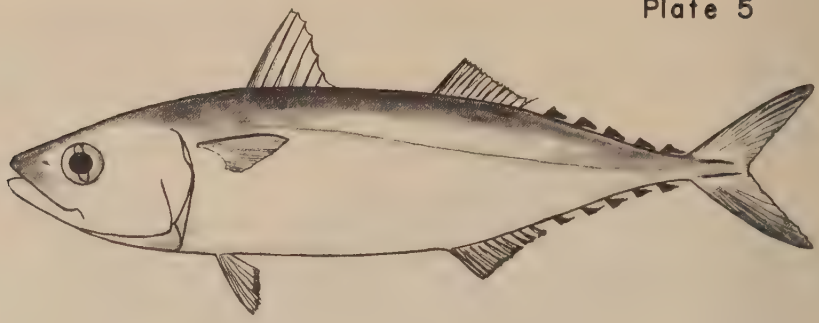


juvenile



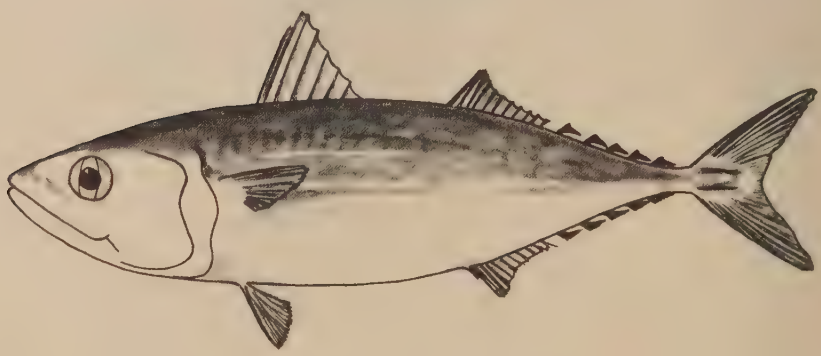
adult

Gasterochisma melampus

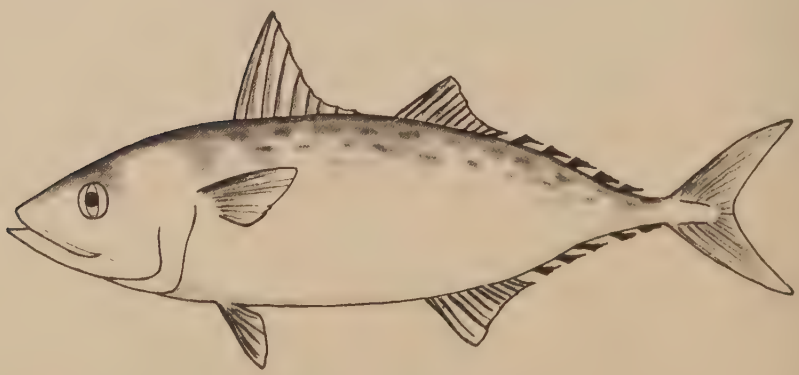


Scomber australasicus

Scomber japonicus

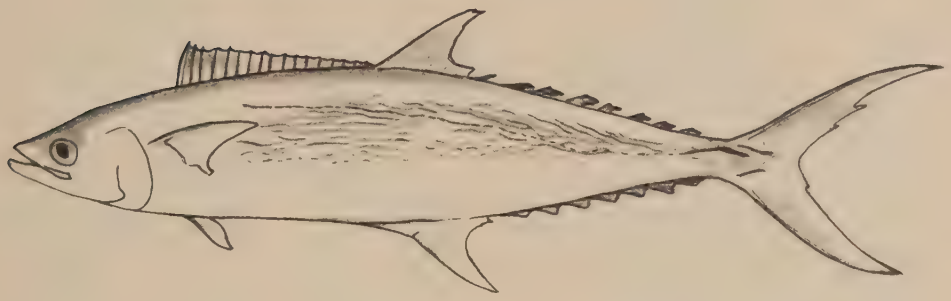


Rastrelliger kanagurta



Rastrelliger brachysoma

Scomberomorus commersoni

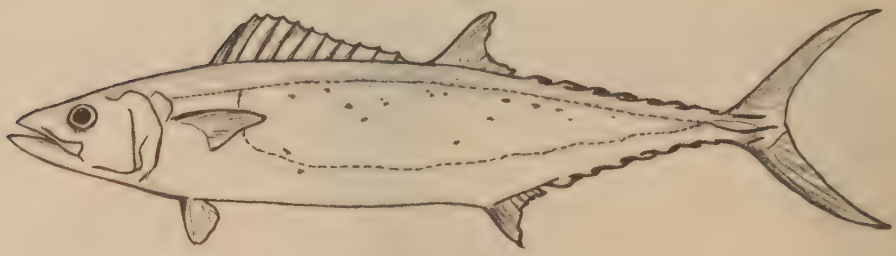


Scomberomorus lineolatus

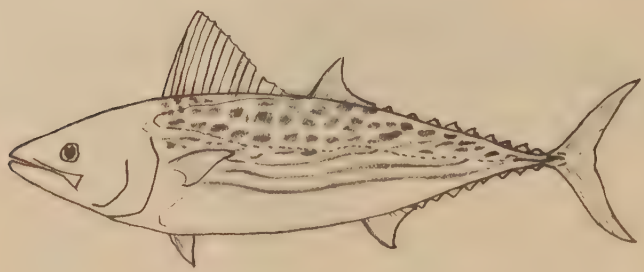
Scomberomorus guttatus

Scomberomorus queenslandicus

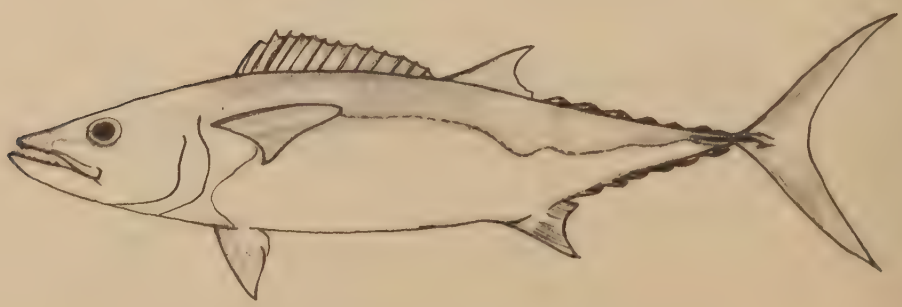
Acanthocybium solanderi



Grammatorcynus bicarinatus

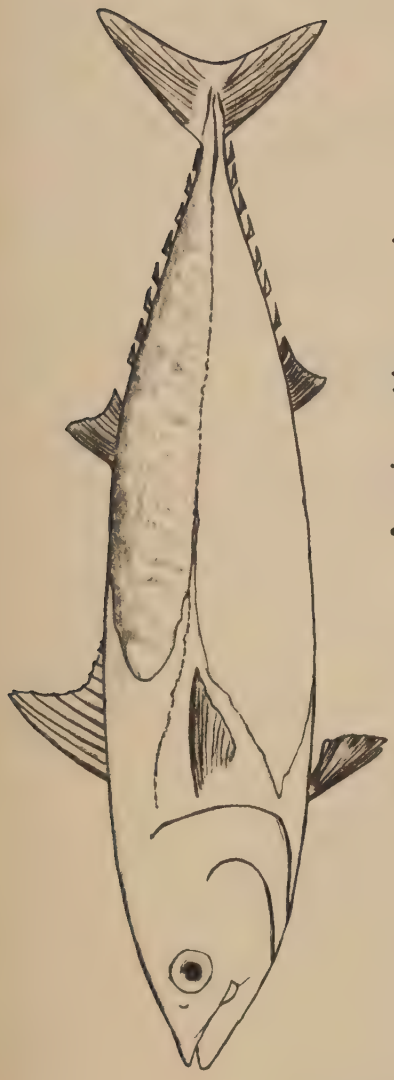


Cybiosarda elegans

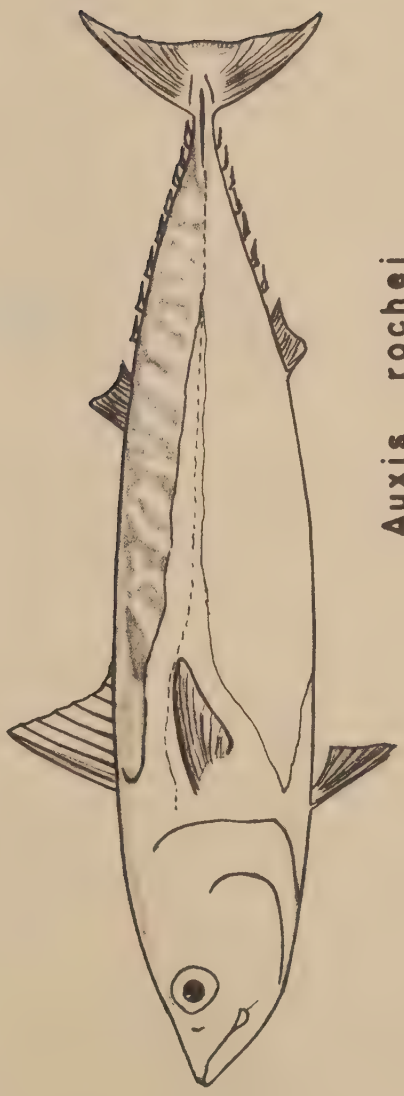


Gymnosarda unicolor

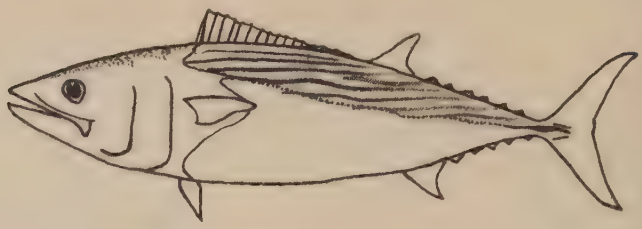
Plate 8



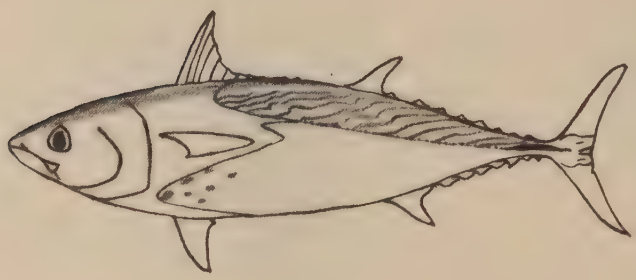
Auxis thazard



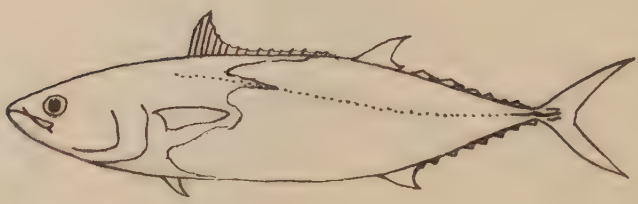
Auxis rochei



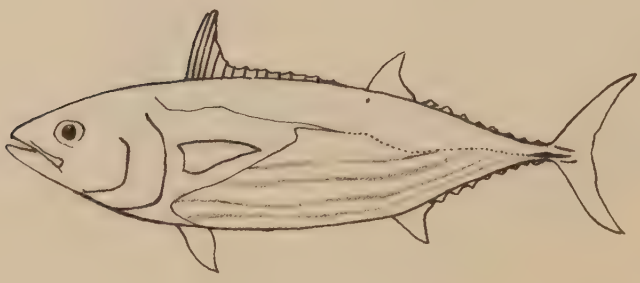
Katsuwonus pelamis



Euthynnus affinis



Allothunnus fallai



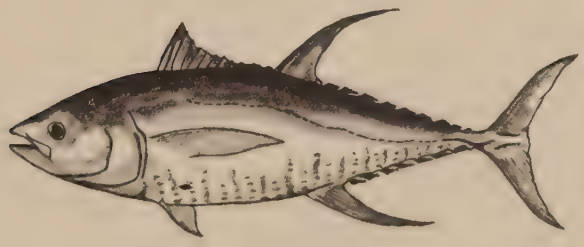
Sarda orientalis

Plate 10

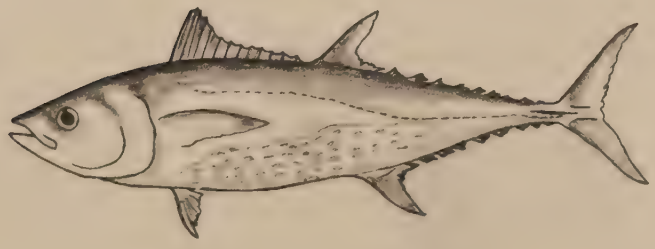
Thunnus alalunga

Thunnus thynnus

Thunnus obesus



Thunnus albacares



Thunnus tonggol

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"CONSERVATION OF WILDLIFE THROUGH EDUCATION"

VOLUME 49 JANUARY 1963 NUMBER 1

THE FIRST CALIFORNIA RECORD OF SIERRA, *SCOMBEROMORUS SIERRA* JORDAN AND STARKS

A 4-pound, 5-ounce mature female sierra, 594 mm fork length, was caught July 10, 1962, from a party boat at the kelp bed off La Jolla. This is the first valid sierra record from California waters (Figure 1).

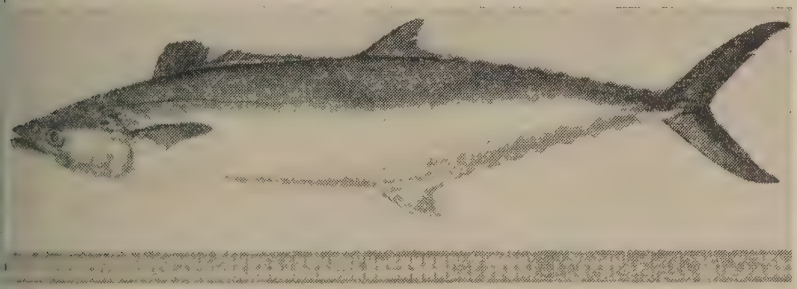

FIGURE 1. Sierra *(Scomberomorus sierra)* caught off La Jolla July 10, 1962. *Photograph by James Rupert, Scripps Institution of Oceanography.*

Sierra have been recorded at one time or another from northern Peru (Hildebrand, 1946, as *S. maculatus*) and the Galapagos Islands (Snodgrass and Heller, 1905) north through the Gulf of California and into southern California (Daugherty, 1946; Fitch, 1949). However, all previous California records refer to the superficially similar Monterey spanish mackerel, *S. concolor* (Lockington) (Fitch and Flechsig, 1949; J. E. Fitch, personal communication). Roedel (1962) wrote that sierra have not been recorded from the State, and we were unable to find California specimens of sierra in the collections of Scripps Institution of Oceanography, University of California at Los Angeles, Allan Hancock Foundation, Stanford University, California Academy of Sciences, or U.S. National Museum.

The previous northernmost published record that definitely refers to sierra is that of Fitch (1950) who reported them abundant along the coast of Baja California and Mexico. We examined a sierra from Bahía Magdalena (Scripps Institution of Oceanography number 60-235-43A) and Eckles (1949) described two juveniles (probably sierra) from Bahía Ballenas.

Sierra differ from Monterey spanish mackerel primarily in having fewer gill rakers on the first arch (4 on the upper limb, 10 to 12 on the lower) and several rows of moderate sized orange-yellow spots on their sides (see color plate 39, Walford, 1937). Monterey spanish mackerel have more gill rakers (5 to 9 + 15 to 20) and few, if any, orange-yellow spots.

We compared our specimen (SIO 62-338) with sierra and Monterey spanish mackerel in the Scripps collection and with the type of *S. sierra* (Stanford University 1720) and found it typical in all respects with sierra described by Jordan and Starks in Jordan (1895) and by Hildebrand (1946). Counts are: gill rakers 4+11=15, first dorsal spines 17, second dorsal rays 16, dorsal free finlets 9, anal rays 17, anal free finlets 7. Color notes, taken while the fish was still fresh,

were: body silver-blue above to silver below; 5 to 6 rows of golden-yellow spots on the sides of the body, all smaller than the pupil of the eye; tail dusky; first dorsal fin yellow, tinged with dusky on the leading edge, black distally, white proximally; second dorsal fin silvery.

Besides being an interesting addition to California's fish fauna and a northward range extension, this represents another typical Panamic species which has gone beyond the tropical zone between Cabo San Lucas and Bahía Magdalena, Baja California (Hubbs, 1960). Radovich (1961) was able to correlate northern captures of typically southern species during 1957-1959 with unusually high water temperatures. Records at the Scripps Institution of Oceanography show that the temperature of local waters has been below the long-term (35-year) average in the period August 1961-August 1962. It is possible the specimen taken in July 1962 had been resident in California waters since the 1959 warm period. We believe, however, it is a recent migrant.

REFERENCES

Daugherty, Anita E.
1946. Rare fishes taken near Los Angeles. Calif. Fish and Game, vol. 32, no. 3, pp. 157-158.

Eckles, Howard E.
1949. Observations on juvenile oceanic skipjack *(Katsuwonus pelamis)* from Hawaiian waters and sierra mackerel *(Scomberomorus sierra)* from the eastern Pacific. Fish Bull., U.S. Fish & Wild. Ser., vol. 51, no. 48, pp. 245-250.

Fitch, John E.
1949. Some unusual occurrences of fish on the Pacific Coast. Calif. Fish and Game, vol. 35, no. 1, pp. 41-49.
1950. Notes on some Pacific fishes. Calif. Fish and Game, vol. 36, no. 2, pp. 65-73.

Fitch, John E., and Arthur O. Flechsig
1949. A brief account of the Monterey spanish mackerel *(Scomberomorus concolor)*. Calif. Fish and Game, vol. 35, no. 4, pp. 275-280.

Hildebrand, Samuel F.
1946. A descriptive catalogue of the shore fishes of Peru. Bull. U.S. Nat. Mus., no. 189, 530 pp.

Hubbs, Carl L.
1960. The marine vertebrates of the outer coast. *In* The biogeography of Baja California and adjacent seas. Syst. Zool., vol. 9, pp. 134-147.

Jordan, David Starr
1895. The fishes of Sinaloa. Proc. Calif. Acad. Sci., ser. 2, vol. 5, pp. 377-514.

Radovich, John
1961. Relationships of some marine organisms of the northeast Pacific to water temperatures, particularly during 1957 through 1959. Calif. Dept. Fish and Game, Fish Bull. 112, 62 p.

Roedel, Phil M.
1962. The names of certain marine fishes of California. Calif. Fish and Game, vol. 48, no. 1, pp. 19-34.

Snodgrass, Robert E., and Edmund Heller
1905. Shore fishes of the Revillagigedo, Clipperton, Cocos and Galápagos Islands. Proc. Wash. Acad. Sci., vol. 6, pp. 333-427.

Walford, Lionel A.
1937. Marine game fishes of the Pacific Coast from Alaska to the Equator. Univ. Cal. Press, Berkeley, 205 p.

—*Bruce B. Collette, Bureau of Commercial Fisheries Ichthyological Laboratory, U.S. National Museum, Washington 25, D.C.; Frank H. Talbot, South African Museum, Cape Town, South Africa; and Richard H. Rosenblatt, Scripps Institution of Oceanography, La Jolla, California; August 1962.*

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ISH-PASSAGE RESEARCH IN THE COLUMBIA IVER BASIN

ERALD B. COLLINS

ureau of Commercial Fisheries, Fish-Passage Research Program, Seattle, Washington

For thousands of years, migrating salmon and steelhead of the olumbia River system have adapted to the conditions prevailing in ifferent parts of the Columbia River Basin. They enter the river, rom the sea, at various seasons of the year: in the spring, in the ummer, and in the fall. Some migrate only a few miles to spawn, hile others swim upstream for more than a thousand miles. Some pawn in large rivers, some in lakes, some in cold mountain streams. ach group in its way has adapted so as to live in harmony with a pecific environmental pattern—with a particular sequence of events, ll of which have meaning to its existence.

Now, in a few short years, the development of the entire river ystem for power, irrigation, navigation, and flood control is making udden, enormous changes in the environments to which the fish ave long been adapted. Where swiftly flowing rivers were, a chain f lakes is being created. Freshets and floods that may have played major role in the transport of fingerlings to the sea are being con- rolled. Temperature regimes that govern rates of growth and ma- uration are being modified. In the changed environments, new redator, competitor, and disease relationships are being established hat may greatly affect the survival of the migrant fish. Add to hese changes the physical barriers to migration created by many ams and the complex nature of fish-passage problems in the Colum- ia River system is made clear.

The necessity for providing methods for the safe and economical passage of migrating fish over the physical obstructions of dams is n obvious one, and a reality that must be faced. An even greater hallenge, however, is the task of anticipating the adaptability of the tocks of fish to migration in the new environments that will be reated by dams and developing methods to protect the fish where

environmental changes may be too severe. All of the factors th affect the behavior and survival of anadromous fish on their migr tions from the gravel to the sea and from the sea to the spawni nest must be considered if we are to provide safe passage for s mon. The need for information is particularly critical in five maj areas:

1. *Effect of Impoundments on Fish Migration.*

A large part of present research effort is directed toward measu ing the effect of impoundments upon the migration of salmon. T basic question to be answered is whether the large impoundmen that would be created by high dams would be impassable barriers migratory anadromous fish. The problem is being studied in lar and small impoundments in Idaho, Washington, and Oregon wi chinook, silver, and sockeye salmon and steelhead trout. The r search on downstream migrants includes estimation of recruitme to the impoundment, noting timing, size, and condition of the m grants; distribution and behavior patterns in the impoundment relation to limnological conditions; estimation of survival a escapement from the impoundment and relation to size, conditio and age of the fish. Orientative behavior of adult salmon releas in the reservoir and the ability of adults to pass through the i poundment and successfully reach spawning areas are beir measured.

2. *Collection and Transportation of Downstream Migrants.*

In anticipation that certain types of impoundments may be i passable to some species (or races) of migrant fish, an importa part of present research is on the development of practical an economical methods of collecting young fish from streams and fro the entrance to impoundments. Methods of fish guidance and colle tion presently in use are only partly successful, or not applicable large projects, or overly expensive. Research is now exploring th possibilities of more effective combinations of techniques that hav shown promise in the past and developing new concepts of fis guidance and collection.

The use of louvers to collect downstream migrants from flowin water is being tested on a large scale at both fixed and floating i stallations. Further experiments with electrical guiding have bee postponed, however, after data from tests indicated that its effectiv ness is limited to velocities of less than 0.5 foot per second. Ne guiding concepts involving the response of fish to changes in wat velocity are being developed and will be tested on a prototype sca

at special test facilities now under construction on the Grande Ronde River in Oregon. The possibility of collecting downstream migrants as they first enter an impoundment is being explored at the Brownlee Reservoir in Idaho, attempting to take advantage of the tendency of the young migrants to stay near the surface. Facilities and methods for holding, handling, and transporting the collected fingerlings are to be studied and tested. An investigation of means of controlling the spread of disease in fish concentrated for transportation purposes is in progress.

3. *Passages at Dams.*

The long sequence of river-run dams that fish must pass through in the Columbia River Basin makes protection at river-run dams an important factor in the survival of upper river stocks of salmon. Research is in progress on means of protecting downstream migrants in turbines, attempting to take advantage of the special distribution of fingerlings in turbine intakes and its relation to the cavitation producing areas that are believed to be the major source of injury to fish. Adult studies are planned to determine the effect of spillway operation on the effectiveness of entrance conditions and on fallback of salmon that have already ascended fish ladders. The relation of fishway-exit location to fallback activity will also be studied. Studies at the Fisheries-Engineering Research Laboratory at Bonneville Dam are directed toward the development of design criteria for effective and economical fishways.

High dams, particularly storage dams with fluctuating forebays and intermittent peaking operations, may not have any satisfactory means of exit from the reservoir available to young fish during the time of migration. Information is being sought on effective methods of providing egress for migrants where no spill is available. Facilities proposed for passage of adults at high dams would in some cases subject the fish to unusual stresses. Studies are in progress to measure the ability of salmon to withstand the conditions that would be imposed.

4. *Racial Physiology and Behavior.*

An important phase of fish-passage research is concerned with the adaptability of racial stocks of salmon to environmental changes anticipated with the construction of dams. Increased effort is being put in the prediction of the effects of proposed new dams on water temperature, oxygen, and flow conditions for analysis in terms of salmon passage and production. In order that the ability of anadromous fish to adapt to such changes in environmental patterns can

be predicted, information is being sought on the limits of the inherent capacities of the fish and how these relate to existing and predicted environmental patterns. A study is being made of racial migration rates and timing, and the nature of the homing mechanism of salmon is being investigated for relation to predicted future conditions.

5. Effect of Temperature Level on Survival and Migration.

The new fresh-water environment being created will determine the potential for success or failure of the upper river stocks of anadromous fish in the Columbia River Basin. In our frantic attempts to solve each set of problems created by each new dam, we are in danger of neglecting more important opportunities to develop some measure of large-scale environmental control that could be of immense benefit to anadromous fish. It is paradoxical that high storage dams that threaten disaster to anadromous fish runs that they intercept also have the potential capacity to control river temperatures within ranges of extreme importance to fish. Maximum water temperatures now reach into the seventies on the Columbia River and into the eighties on the Snake River. Unfortunately, the planning of the great storage reservoirs on the upper Columbia River includes no attempt to provide downstream temperature control. It would be extremely shortsighted if a similar situation were permitted to develop on the Snake River. Research is needed on the direct effect of water temperature on the migratory behavior and survival of anadromous fish. To fully appraise the benefits to be gained by control of water temperature, however, information is also needed on the effects of water temperature level upon disease and upon warm-water species of fish that compete with and prey upon anadromous fish as they pass through the long sequence of impoundments during their migration.

DISCUSSION

MR. A. T. PRITCHARD [Washington State Game Commission]: My remark is not directed as a question but the matter of a statement which was in the paper. I think particularly our people in the central part of the United States and eastern part of the United States are not aware of some conditions of the high dams which haven't been covered in this paper. On normal dam structures fish migrating upstream seem to get through quite well on the basis of not being handled, but we get into the problem of our higher dams, like the Lewis River and Callas River Dams in Washington where they are using a British-type operation. I think this is something we should be a little more cognizant of in your unprotected stock. At the Lewis River, it took 10 years to kill off a spring run salmon population. This was done again through an elevator-type and a handling operation. We have gone into a similar type of operation in the south again with the Braille, and to cite an example, the Game Department of the State of Washington trailed as carefully as we could some stocked steelhead, which is a very important fish in these streams, and we moved them no greater distance then than they are moving the

sh in California today. We took 60 fish, handling them very very carefully, and a period of two months, we lost every single fish. This was with extreme care, ot in the manner they are doing at the present time on the Callas River, where with e brailling they have a short ladder system. They go into a traveling braille peration, are dumped into a truck and hauled several miles and dumped back in ehind the dam. I am afraid that our people are not making progress. It is a point want to bring out. We should look a little harder at this point.

MR. FISHER: Thank you very much. Mr. Collins mentioned here studies on ientative behavior of adult salmon. I might mention briefly in passing the udies on orientation and celestial navigation of downstream migrants, and I ink some downstream migrants, too, being carried out by British Columbia, and am on the research board. One factor, as I remember, from a summer ago up ere is in any positioning of the behavior that they have discovered from their udies on celestial star and sun navigation, and positioned behavior in down-ream migrants, that they take up even when experimental leads indicate that it in total darkness, the point being that here, possibly, is another complex factor the design of fish passages. It may be of great advantage to design in such a ay as to interfere as little as possible with the steelhead in a group orientation ehavior.

A VOICE: I'm from Oregon. I would just like to make a little amplification of r. Collins' paper. Dr. Collins is aware, as we have discussed it and that is the atter of water quality that we get into on a number of projects. We used to ink we could put the fish over any dam merely by building a ladder and the fish ould go up. This proved true on our main attempts on Columbia River dams ad a lot of other western dams. However, some of the smaller areas where we rst started looking matters over, in dams that created stratified reservoirs, we ound that in the summer areas, these conditions developed a different type of aterfall in coming down a fish ladder than was issuing from the turbines, with the esult that the fish refused to enter fish ladders because the flow was different than at in which they approached the obstruction. This is a factor we are recognizing ow on the West Coast and there are ways of getting around it. However, I was a ttle bit concerned about some of this work being done and proposed for the Sus-uehanna and some streams on the East Coast because there is every chance that ie same thing will happen there, and I see no visions for adding discussions that on't add anything, and I think it is something that could well be taken advantage f and studied in advance before several million dollars are spent for fish ladders at prove utterly unacceptable to fish.

MR. ARNOLD GOLD [Oregon State Game Commission]: I would like to elaborate n one facet here of Dr. Collins' paper. When he speaks of racial stocks, let me oint out that in my opinion what he is talking about is the various races of a ngle species. The spring run of fish, for example, in the Columbia has a great umber of racial stocks. In other words, there are those that are going up the ollins about which the gentleman just spoke. There are those who go up the [elena, up the Fuse, and a variety of other streams that connect to the Salmon iver in Idaho. You will find those fish are entering the main stem of the Colum-ia at different times. They have different spawning times. For instance, the mneha River in Oregon which empties into the Snake River, slightly upstream nd across from the Salmon, the fish, the spring chinook—the species is the same —are spawned out a substantial length of time before those in the Salmon River, hile the spring chinook that are inhabiting the McKenzie River, a tributary to he Linan, won't be spawned out until summer and mid-September. Those of the mneha will have spawned and died by the middle of August. The same situation pplies to practically every species of salmon using that river. I might point out n the Rogue River, which is completely separate from this, we can at the present ime identify seven different races of steelhead alone. There may be more.

MR. FISHER: Thank you very much for finding out your problems. I think erhaps we should move on.

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pp. 447–450

THE EGGS AND LARVAL STAGES F THE BUTTERFISH, *PORONOTUS RIACANTHUS*. — The identification of e eggs and prolarvae of butterfish, *Poron-s triacanthus* (Peck), has proved trouble-me owing to the confusion in the litera-re between this species and the red hake, *ophycis chuss* (Walbaum). Miller and arak (*Copeia 1959:248–50*) summarized e existing literature concerning the early velopmental stages of these two species d described prolarval red hake hatched m artificially fertilized eggs.

The following description of butterfish gs and prolarvae was obtained from a udy of artificially fertilized eggs stripped om fish caught in a commercial fish trap Pemaquid Point, Maine, on 31 July 1961. After fertilization the eggs were placed in o-gallon hatching jars set in a bath of nning sea water. Water in the hatching rs was changed daily. No attempt was ade to feed the developing larvae; the last ne died on the tenth day, at the time of tal yolk sac absorption. Photographs were ken of living specimens and a daily sam-e of 20 larvae was preserved in 5 per cent rmalin. The average temperature of the ater in the hatching jars during this pe-riod was 14.6° C, with a range from 13.3 to 16.8° C. Examination of these specimens and a review of the literature revealed that our late-stage eggs and prolarvae were the same as those erroneously described for the bluefish, *Pomatomus saltatrix* (Linnaeus), by Agassiz and Whitman (1885, *Mem. Mus. Comp. Zool. 14[1]:1–56*). We have referred to their excellent colored illustrations where relevant.

Eggs

The average diameter of the transparent, spherical eggs two hours after fertilization based on measurements of 200 living eggs was 0.77 mm; the range was 0.75 to 0.79 mm. A single oil globule with an average diameter of 0.20 mm (range 0.17 to 0.21 mm) was found in 70 per cent of the eggs. The remaining 30 per cent had 2 or 3 oil globules which ranged in diameter from 0.06 to 0.16 mm. As development advanced these separate oil globules coalesced into one, but a few eggs had several oil globules at the time of hatching. Twenty-four hours after fertilization the formation of the blastodermal cap was completed. Forty-eight hours after fertilization the blastopore was closed or was closing and the eye became differentiated. Fifty-six hours after fertiliza-

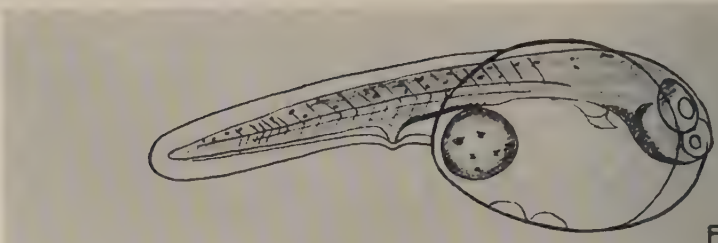

FIGURE 1.

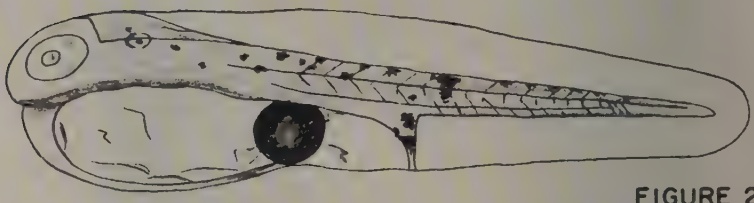

FIGURE 2.

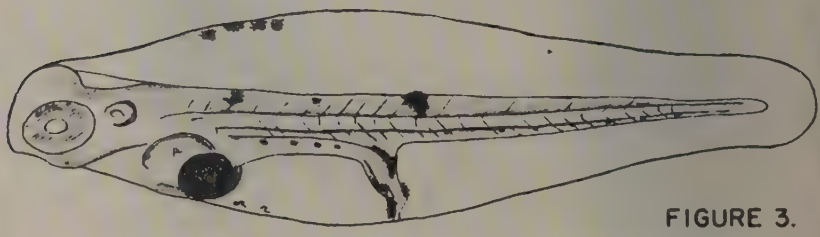

FIGURE 3.

FIGURE 4.

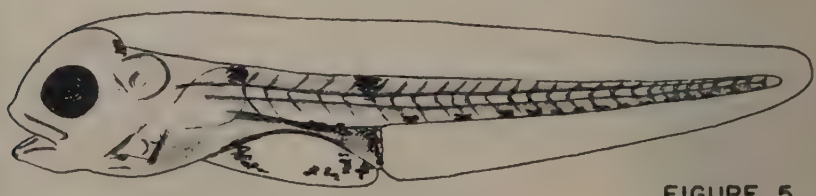

FIGURE 5.

Fig. 1. *P. triacanthus* at hatching, 1.70 mm. Fig. 2. *P. triacanthus* 24 hours after hatching, 2.
mm. Fig. 3. *P. triacanthus* 72 hours after hatching, 2.67 mm. Fig. 4. *P. triacanthus* 144 hou
after hatching, 2.51 mm. Fig. 5. *P. triacanthus* 168 hours after hatching, 2.50 mm.

n the tail had formed, and light, scattered pigment appeared on the oil globule and on the dorsum of the embryo from an area just posterior to the eyes and extended in two rows to the end of the tail as illustrated by Agassiz and Whitman (*op. cit., Pl. 4, Fig. 6*). Seventy-two hours after fertilization approximately 50 per cent of the eggs had hatched. The eggs of butterfish differed from those of the red hake described by Hildebrand and Cable (1938, *Bull. U. S. Bur. Fish. 48:615–6, Figs. 124–6*) in (1) a slightly greater size of the oil globule, (2) the smaller size and amount of pigmentation on the embryo and oil globule, (3) lack of pigmentation on the yolk, and (4) the lack of pigmentation on the eye of the late-stage embryo.

Larvae

At hatching (Fig. 1).—Newly hatched larvae averaged 1.72 mm in length, ranging from 1.68 to 1.75 mm. Pigmentation was similar, but more pronounced than that of the 56-hour embryo. The light body pigmentation was confined to the dorsal and dorsolateral surfaces in two dorsal rows of small melanophores extending posteriorly from the head to the tail. The oil globule, located at the posterior end of the yolk sac, was lightly pigmented with two or three stellate melanophores. The eye was unpigmented. The vent, located some distance from the posterior margin of the yolk sac and a little more than half the length of the body from the anterior end, opened at the margin of the finfold.

Twenty-four hours after hatching (Fig. 2). Growth in the 24-hour period following hatching was considerable. The average length of the 24-hour larvae was 2.27 mm, and the range 2.14 to 2.44 mm. The head extended beyond the yolk which was considerably reduced, the eye was still unpigmented, and the dorsal and dorsolateral chromatophores became aggregated into well-defined masses. The pigmentation, which consisted principally of yellow-brown chromatophores, was confined primarily to the anterior two-thirds of the body. The most diagnostic characteristic of the 24-hour larvae was two concentrations of pigmentation, one on the dorsal aspect of the body just posterior to the vent and the other at the vent (Agassiz and Whitman, *op. cit., Pl. 4, Fig. 7*).

Forty-eight hours after hatching.—The average length of the 48-hour larvae was 2.49 mm, and the range 2.37 to 2.61 mm. The yolk mass was further reduced, the eye still unpigmented, and the larvae appeared deeper bodied because of the more pronounced arching of the dorsal and ventral finfolds. The areas of concentrated yellow-brown pigmentation on the dorsum just posterior to the vent and at the vent became more distinct. Yellow-brown pigment spots began to appear on the edge of the dorsal finfold. The chromatophores in the trunk region were concentrated in an area above the oil globule and a row of fine melanophores appeared along the base of the ventral finfold posterior to the vent (Agassiz and Whitman, *op. cit., Pl. 4, Fig. 8*).

Seventy-two hours after hatching (Fig. 3).—The average length of the 72-hour larvae was 2.60 mm, and the range 2.48 to 2.71 mm. The pigmentation was still predominantly yellow-brown and distributed as in the 48-hour larvae, although the ventral row of melanophores and the yellow-brown pigment spots on the dorsal finfold became more distinct. The yolk mass was further reduced and the eye was still unpigmented. No significant increase in the average length of the larvae was noted after this period.

Ninety-six hours after hatching.—The average length of the 96-hour larvae was 2.61 mm, and the range 2.48 to 2.67 mm. No appreciable changes in morphology or pigmentation occurred during this period. The yolk sac and oil globule were further reduced, the ventral row of melanophores was slightly more distinct, and the yellow-brown pigment spots on the dorsal finfold had decreased in size (Agassiz and Whitman, *op. cit., Pl. 4, Fig. 10*).

One hundred twenty hours after hatching.—The average length of the 120-hour larvae was 2.60 mm, and the range 2.48 to 2.64 mm. The most notable changes were that the upper part of the eye was pigmented black and the intestine and mouth were well developed. The oil globule was almost completely absorbed and the pectoral fins were conspicuous. The pigmentation was still predominantly yellow-brown, the ventral row of melanophores was distinct, and the yellow-brown pigment spots on the dorsal finfold had decreased in number and size or had disappeared.

One hundred forty-four hours after hatching (Fig. 4).—The average length of the few

larvae measured was 2.57 mm. The yellow-brown pigmentation was less prominent and in some specimens had completely disappeared from the dorsal aspect of the body. The eyes were almost completely pigmented, and the pectoral fins well developed. The melanophores above the intestine and along the ventral aspect of the tail had increased in size. In most larva the oil globule was completely absorbed. The ventral row of pigmentation posterior to the vent along the tail was the most diagnostic characteristic of the larvae at this stage. With the exception of the blue coloration of the eye, these larvae were identical to the 9-day-old larva pictured by Agassiz and Whitman (*op. cit., Pl. 5, Fig. 11*).

One hundred sixty-eight hours after hatching (Fig. 5).—Only one specimen was still alive at this time. This larvae exhibited all the characteristics of the 144-hour larvae, but the area and intensity of the yellow-brown pigmentation was reduced and the 30 myomeres were readily discernible. The distribution of black pigmentation of the 144- and 168-hour larvae was similar to that of the 2.8-mm butterfish postlarva pictured by Perlmutter (1938, *N. Y. Conserv. Dept. Suppl. 28th Ann. Rept. 15:11–71*). The yellow-brown pigmentation apparently disappears in the later stages of development and the larvae become deeper bodied as pictured by Perlmutter.—John B. Colton, Jr., *U. S. Bureau of Commercial Fisheries, Biological Laboratory, Woods Hole, Mass.,* and Kenneth A. Honey, *U. S. Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine.*

23.

The Use of Stains in Shrimp Mark-Recapture Experiments

By

T. J. COSTELLO*

Petersen tags have been used with some success to mark the white shrimp, *Penaeus setiferus*, (Lindner and Anderson, 1956) and the pink shrimp, *P. duorarum*, (Iversen and Idyll, 1960). However, small shrimp, because of their general frailty, suffer excessive mortality during or shortly after the tagging process. Thus, an undesirable restriction of the tagging method in shrimp population studies is that tagged populations consist only of large and robust individuals, in which the recurrence of molting is minimal. In addition, shrimp agility and mobility are believed impaired by tags, limiting still further the method's utility as a research tool.

On the basis of small-scale laboratory trials with the white shrimp, *P. setiferus*, Menzel (1955) reported that injection of a biological stain, which concentrated and remained fast in the shrimp's gill filaments, promised a more feasible means of marking penaeid shrimp. Under contract with the U. S. Bureau of Commercial Fisheries, Dawson (1957) expanded on the staining technique and reported four vital dyes that seemed useful for this purpose. During 3 years of experiments in which 146,500 shrimp were stained and released in the South Atlantic Ocean and Gulf of Mexico, Costello (1959) and Costello and Allen (1960) demonstrated the utility of this method for studying shrimp movements and growth. Refinements in staining techniques and increasingly efficient field procedures evolved from these experiments.

Methods

Successful shrimp marking requires that experimental animals be held at temperatures and salinities most conducive to their survival. It is also important to time the staining process so it will not be undertaken while high proportions of shrimp are in a "soft-shelled" condition. A high rate of mortality will prevail if shrimp are handled and stained too soon after ecdysis.

Preferably, the sites of shrimp capture, staining, and release should be contiguous, so as to maintain uniform conditions throughout the marking operation and to eliminate the need for transporting marked shrimp any great distance.

When obtaining animals for marking it is suggested that, where possible, an experienced commercial fisherman, especially one familiar with techniques in handling live shrimp, be contracted to obtain suitable quantities of shrimp in good condition.

When a study of growth rates is planned, shrimp of uniform size must be released. A simple and efficient device for separating shrimp into size groups is described by Allen and Costello (1961).

For holding shrimp prior to marking, small floating "live cars" consisting of wood frames covered with hardware cloth are useful. Twenty-four-gallon plastic garbage cans perforated with $^1/_4$-inch holes and supported in the water by automobile tire inner tubes serve equally well. A table with inset trays to hold shrimp just prior to marking facilitates the staining operation. The table should also be fitted with a trough in which freshly stained shrimp are carried by means of running sea water to a suitable holding tank. Other equipment such as water pumps, hose systems, etc., must be arranged to suit the particular field situation.

Trypan blue (C. I. No. 477), Trypan red (C. I. No. 438), fast green (FCF, C. I. No. 42053), and Niagara sky blue 6B (C. I. No. 518) have proved to be the best dyes for marking shrimp. More than any other factor, the care with which stain solutions are prepared controls the success of shrimp staining experiments. The following important points should be considered when making solutions:

(1) Sterile distilled water is the preferred solvent.
(2) Solutions should be filtered through Whatman No. 1 filter paper or equivalent.
(3) Stains differ according to manufacturer. Fast green manufactured by the National Aniline Co., and Trypan blue, Trypan red, and Niagara sky blue 6B manufactured by Harleco are recommended.
(4) Stain solutions must be freshly prepared, since in solution they become toxic with ageing.

Shrimp are injected at the articulation of the fourth and fifth abdominal segments. Care should be taken to avoid puncturing the hindgut. One-half-cc tuberculin syringes fitted with $^1/_4$-inch hypodermic needles (27 or 30 gauge) are recommended for injecting shrimp of all sizes.

The quantity and strength of stain solution required vary according to the type of stain and size of shrimp. For a pink shrimp 130 mm long, 0.07 ml of a 0.25 percent solution of Trypan blue, 0.18 ml of a 0.5 percent solution of fast green (FCF), or 0.09 ml of a 0.5 percent

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International Commission for the Northwest Atlantic Fisheries, North Atlantic Fish Marking Symposium, Woods Hole, Massachusetts, May 1961, Special Publication no. 4, p. 142-143, 1963.

solution of Trypan red are optimum. Only freshly prepared solutions should be used. Shrimp can be injected at the rate of 300 to 350 per hour per man.

Field tests with Trypan blue and fast green indicate that these stains remain fast over a period of at least 6 months. Trypan red is subject to some fading. No field tests have been conducted with Niagara sky blue 6B.

To eliminate from any experiment specimens that do not immediately recover from handling shock, marked shrimp should not be released for at least 4 hours following injection of the staining solution. Releases should be made in areas where undue predation by fishes at the time of release can be avoided.

Because stained shrimp are not as easily detected as tagged shrimp, greater stress must be placed on the recovery phases of mark-recapture experiments using stains as marking agents. Stained shrimp are readily recognized by trained personnel but not by commercial fishermen, upon whose coöperation in recognizing and returning marked specimens the success of each experiment depends. Shrimp staining experiments have proved most successful when they have been widely publicized, when sizeable rewards have been offered for recaptures, and when carefully planned and complete coverage has been given to landing ports.

Summary

The usefulness of biological stains for marking penaeid shrimps has been demonstrated. The staining method is simple, rapid, and suitable over a wide range of shrimp sizes. Successful application of the staining method in mark-recapture experiments requires: (1) careful handling of shrimp; (2) correct timing of each experiment so as to avoid too high a proportion of soft-shelled (molting) animals; and (3) injection of recommended amounts of properly prepared stain solutions. The method's disadvantages are: (1) animals recaptured by commercial fishermen are not as easily recognized as tagged shrimp and (2) for purposes of growth estimation, experimental shrimp must be of uniform size when released.

References

ALLEN, D. M. and T. J. COSTELLO. 1962. Grading large numbers of live shrimp for marking experiments. *Progr. Fish. Cult.*, **24** (1): p. 46—48.

COSTELLO, T. J. 1959. Marking shrimp with biological stains. *Proc. Gulf Caribb. Fish. Inst.*, 11th Ann. Sess., 1958, p. 1—6.

COSTELLO, T. J. and D. M. ALLEN. 1960. Notes on the migration and growth of pink shrimp (*Penaeus duorarum*). *Proc. Gulf Caribb. Fish. Inst.*, 12th Ann. Sess., 1959, p. 5—9.

DAWSON, C. E. 1957. Studies on the marking of commercial shrimp with biological stains. *Spec. Sci. Rep. U. S. Fish Wildl. Serv.* No. 231, 23 p.

IVERSEN, E. S. and C. P. IDYLL. 1960. Aspects of the biology of the Tortugas pink shrimp, *Penaeus duorarum*. *Trans. Amer. Fish. Soc.*, **89** (1): p. 1—8.

LINDNER, M. J. and W. W. ANDERSON. 1956. Growth, migrations, spawning and size distribution of shrimp, *Penaeus setiferus*. *Fish. Bull.*, U. S., **56** (106): p. 553—645.

MENZEL, R. W. 1955. Marking of shrimp. *Science*, **121** (3143): p. 446.

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Issued from the Headquarters of the Commission
Dartmouth, Nova Scotia, Canada
1963

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7.

The Movement, Heterogeneity, and Rate of Exploitation of Walleyes in Northe Green Bay, Lake Michigan, as Determined by Tagging

By

WALTER R. CROWE*, ERNEST KARVELIS**, and LEONARD S. JOERIS**

Introduction

The Michigan waters of northern Green Bay are an important center for commercial and sport fishing. This 400-square-mile area has supported a commercial fishery for many years but the development of the intensive sport fishery is more recent,mostly since World War II. The commercial fishery is based on several species, whereas anglers are particularly interested in the walleye, *Stizostedion v. vitreum*.

Broad objectives of tagging studies initiated in September 1957 were to obtain information on the heterogeneity, movement, and exploitation of the walleye population of northern Green Bay. The statistical data on the commercial fishery are very sound but other information on the Green Bay walleye has been sketchy.

Shortages of personnel and money have limited the numbers of walleyes that could be tagged and have placed undesirable restrictions on the time and locality of tagging. Our early findings have, nevertheless, brought out some useful information and have indicated rather clearly the lines along which further tagging experiments should be organized. The present article is concerned with some of the special uses of tag-recovery data that should prove profitable in Green Bay.

Methods

Tags were applied to a total of 4,690 walleyes — 770 in 1957, 917 in 1958, 1,981 in 1959, and 1,022 in 1960. Total lengths, which were recorded at tagging, ranged from about 10 inches upward to 30 inches but 68.6 percent of the fish were at or above $15^1/_2$ inches, the minimum size for commercial fishermen. (The minimum for anglers is 13 inches.) Most of the tagging was done in the early spring. Walleyes were tagged at 14 different localities (Fig. 1) but most were released at three sites: 1,480 (32 percent) at a sea lamprey barrier on the Whitefish River; 1,777 (38 percent) in the extreme northern end of Little Bay de Noc, and 314 (7 percent) in Big Bay de Noc, near Nahma. The geographical distribution of t tagging sites in the initial stages of this study w governed largely by the availability of fish.

Most of the fish were marked with monel-met tags (Shetter, 1936) placed around the maxillary a premaxillary, or "spaghetti-dart" tags (Yamashita a Waldron, 1958) inserted immediately below the s dorsal fin. Other types were placed on too few fi to have any bearing on results given in this repo The reports of recapture for the two principal kin of tags have been closely similar.

Recaptures of tagged walleyes were report voluntarily by anglers and commercial fishermen; rewards were offered. Fishermen were alerted to t presence of tagged walleyes by the local press, posters at boat liveries, fish houses, and public-acc points, and by word of mouth. To stimulate continu coöperation, all reports of recapture were acknowle ged with a form letter giving locality, date, a length of fish at tagging. In addition to the recaptu reported by fishermen, we took numerous tagg walleyes in our own nets.

Homogeneity and Heterogeneity of the Walleye Populati

The walleyes remained in Green Bay and most the recaptures were in the northern part. Of 417 fi reported by anglers and commercial fishermen on 5 had left northern Green Bay; all of these were captured in central or southern Green Bay. No have been reported from Lake Michigan prop Results of this and earlier experiments (Eschmey and Crowe, 1955) indicate that the walleye stoc of Lake Michigan are local.

Evidence of homogeneity of the walleye stock northern Green Bay comes from extensive po spawning intermingling of fish tagged during t spawning run. Anglers and commercial fisherm have reported the recapture of tagged walleyes in areas at most times of the year.

Despite the general mixing through much of t year, our own recaptures during the spawning seas of fish tagged from previous spawning runs gi strong evidence that the northern Green Bay walle population is subdivided into discrete spawning uni Nearly all (72 of 76) recaptures during the spawni

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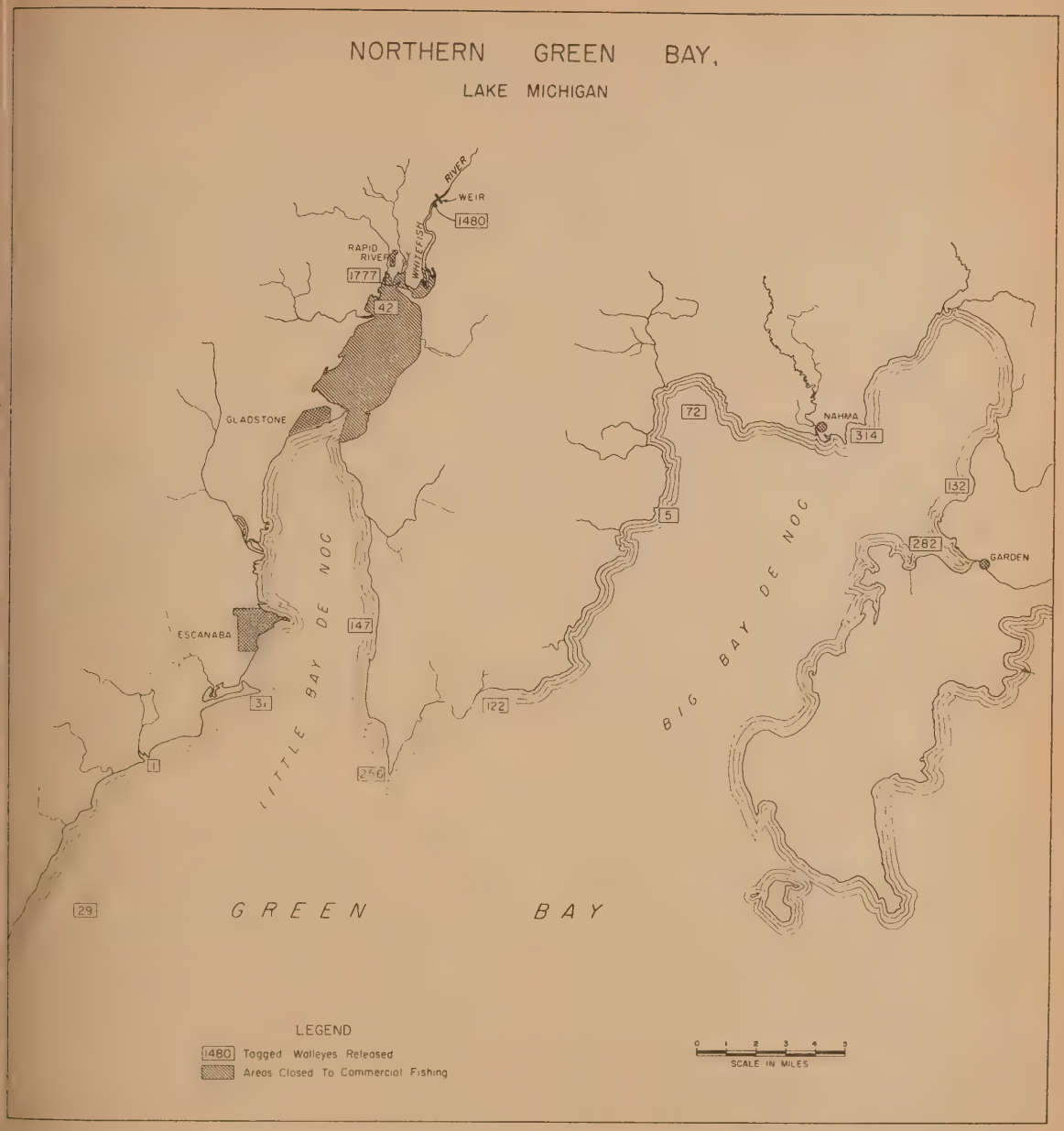

Figure 1. Location of tagging localities and number of walleyes tagged at each site. The shaded area is closed to commercial fishing.

period were made at or very near the point of release. Of 65 recaptures in northern Little Bay de Noc, 64 had been released there; of 11 recaptures near the lamprey weir on the Whitefish River 8 had been released there. Our first spawning-season fishing near Nahma in Big Bay de Noc in 1960 did not, on the other hand, yield a single fish tagged at other spawning localities in previous years. Results to date, then, give rather strong evidence that the walleye population of northern Green Bay breaks down into distinct subpopulations during the spawning season. These subpopulations are identified with particular spawning sites; at the approach of spawning, walleyes return to their chosen grounds and do not merely move

randomly to any suitable grounds. Tagging at a greater number of sites is needed to give more information on this point.

The existence of discrete spawning units within populations has long been known among certain species, particularly the salmonids, but little is known about fish that spawn in the open water or, as the walleye, facultatively in the lake or in a tributary. The only previous indication in the Great Lakes that a characteristically open-lake spawner may return annually to the same spawning grounds was obtained by the returns of tagged spawning lake trout in Lake Superior (Eschmeyer, 1955). Stream-spawning lake trout, known only in certain tributaries of northeastern Lake Superior, have been shown conclusively to return annually to the same streams (Loftus, 1958).

Exploitation by Sport and Commercial Fishermen

Sport fishermen long have angled for walleyes in northern Green Bay, particularly in the more northerly part of Little Bay de Noc where the confined waters are usually safe for small boats. This fishery expanded rapidly following World War II, especially in the late 1940's and in the early and middle 1950's. A prime factor in the growth of the sport fishery for walleyes was the phenomenal strength of the 1943 year-class which continued important into the 1950's; the general growth of the tourist travel also furthered the great expansion of tourist facilities.

Although the growth of the sport fishery has been obvious, opportunities to measure its true extent have been lacking. Money and personnel were far too limited for the establishment of an effective creel census. The reported recaptures of tagged walleyes, however, now suggest a procedure which conceivably may supply a reasonably sound estimate of the take of anglers. This estimate is based on the application of data on relative numbers of tags reported by sport and commercial fishermen to the statistics on commercial production and data on the average weight of walleyes in commercial landings.

This procedure can be illustrated from the records for 1958. The commercial take in that year amounted to 206,000 pounds and the mean weight of commercially landed walleyes examined by staff members of the Bureau of Commercial Fisheries was 1.73 pounds; the number of fish caught by commercial operators is estimated as 119,000.

In 1958 anglers reported 52.8 percent and commercial fishermen 47.2 percent of the walleyes that were $15^1/_2$ inches long or larger at the time of tagging (Table 1); the anglers' take of these larger fish is then estimated to have been 133,000 fish. The estimate of the full take of anglers must include the additional fish down to 13.0 inches. Since 68.3 percent of all fish caught by anglers in 1958 (Table 2) were in the size range 13.0—15.4 inches, their catch is increased by an estimated 287,000 and the total becomes 420,000. The total removed by sport and commercial fisheries in 1958 amounts then to 539,000 fish.

Table 1

Reported recapture of tagged walleyes, $15^1/_2$ inches and over at time of tagging, through 31 December 196

	Group of fishermen reporting			
	Sport fishermen		Commercial fishermen	
Year of recapture	Number of recaptures reported	Percentage of total reports	Number of recaptures reported	Percentag of total reports
1958	19	52.8	17	47.2
1959	89	74.8	30	25.2
1960	68	68.0	32	32.0
Total	176	69.0	79	31.0

Table 2

Size at time of tagging for walleyes recaptured and reported by anglers to 31 December 1960

	Size range (inches)			
	13.0—15.4		> 15.4	
Year of recapture	Number of recaptures reported	Percentage of fish within length interval	Number of recaptures reported	Percentag of fish within lengt interval
1957*	6	100.0	...	...
1958	41	68.3	19	31.7
1959	46	34.1	89	65.9
1960	9	11.7	68	88.3
Total	102	36.7	176	63.3

* 97.9 percent of the fish tagged in 1957 were under 15.5 inche

Actually, the estimates of the sport-fishery catc and hence of total removal cannot be accepted a closely accurate. The present data indicate tha anglers capture many more walleyes than do com mercial fishermen, but sources of bias that prohibit more definite statement of relative numbers taken a clearly apparent and others may be uncovered as th tagging proceeds.

More small walleyes should have been tagged improve the estimate of take by anglers; 68.6 perce of all the walleyes tagged were at or above the com mercial minimum legal length of $15^1/_2$ inches, b sport fishermen take great numbers of fish betwee 13 and $15^1/_2$ inches (Table 2).

The distribution of tagging localities has tended produce an overestimate of the take of anglers. (the total of 4,690 walleyes tagged, 3,257 or 69.6 perce were marked in late April or early May in the extren northern part of Little Bay de Noc (or a tributar in waters closed to commercial fishing. This ar includes the major angling waters (Fig. 1). The spawning-run fish moved gradually southward aft tagging, but when fishing started on May 20 at t

ıd of the spring closed season (April 1—May 20) me were still in the closed area, where they were hed heavily by anglers but were not available to ɔmmercial fishermen. More fish should be tagged Big Bay de Noc, in the lower part of Little Bay de oc, and in the open water to the south.

We need also more precise knowledge of the growth walleyes so that we can judge better the time terval that must be allowed before undersized fish various lengths are to be considered vulnerable to ıe sport or commercial fishery.

Summary

The walleye, *Stizostedion v. vitreum*, long a valuable ɔmmercial fish in the Michigan waters of northern reen Bay has become, since World War II, a very ıportant sport fish. A tagging study was initiated in ɛptember 1957 to obtain information on the hetero-ɛneity, movement, and exploitation of the walleye ɔpulation. The fish were tagged with monel-metal w tags or spaghetti-dart tags. Returns from tags ıdicated that walleyes remained in the northern ıd of Green Bay, but fish from different spawning ites mixed after spawning. Recaptures during the ɔawning season of fish tagged from previous spawning ıns gave strong evidence that the walleye population subdivided into discrete spawning stocks.

In 1958, commercial fishermen are estimated to ave caught 119,000 fish, and anglers took an estimated 420,000 fish — a grand total of 539,000. The estimate of the numbers caught by commercial fishermen was based on statistical records of production and the weighing of samples from commercial landings. The estimate of the number caught by sport fishermen was based on the ratio of the numbers of tags returned by commercial fishermen and anglers. Inadequacies in the marking program as conducted to date, and explained briefly in the text, prohibit acceptance of the estimate of take in the sport fishery as closely accurate. Improvements of procedure and analysis should make possible a satisfactory appraisal of the total catch in a sport fishery where a creel census is impractical.

References

ESCHMEYER, PAUL H., and WALTER R. CROWE (1955). The movement and recovery of tagged walleyes in Michigan, 1929—1953. *Mich. Dept. Cons., Inst. Fish. Res., Misc. Pub.* 8. 32 p.

ESCHMEYER, PAUL H. (1955). The reproduction of lake trout in southern Lake Superior. *Trans. Amer. Fish. Soc.*, 84 (1954): 47—74.

LOFTUS, K. H. (1958). Studies on river-spawning populations of lake trout in eastern Lake Superior. *Trans. Amer. Fish. Soc.*, 87 (1957): 259—277.

SHETTER, DAVID S. (1936). The jaw-tag method of marking fish. *Pap. Mich. Acad. Sci,*. 21 (1935): 651—653.

YAMASHITA, DANIEL T., and KENNETH D. WALDRON (1958). An all-plastic dart-type fish tag. *Calif. Fish Game*, 44 (4): 311—317.

Schmidt & Klaunig, Kiel

Pub. No. 10, Great Lakes Research Division, The University of Michigan, 1963

QUANTITATION OF MICROORGANIC COMPOUNDS IN WATERS OF THE GREAT LAKES BY ADSORPTION ON ACTIVATED CARBON

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Abstract

Microorganic compounds in waters of Lakes Michigan and Huron have been sampled by adsorption on activated carbon in filters installed aboard the M/V *Cisco* and at the Hammond Bay Laboratory of the U. S. Bureau of Commercial Fisheries. The organic compounds were eluted from the carbon according to techniques developed at the U. S. Public Health Service.

On the assumption that chloroform eluates represent less polar compounds from industrial sources and alcohol eluates the more polar varieties of natural origin, plots of chloroform eluates against alcohol eluates appear to be useful in judging water qualities. Based upon these criteria, the data in this paper indicate that both the waters of northern Lake Michigan and of Lake Huron, in the vicinity of Hammond Bay, Michigan, are relatively free from pollution. The limnetic waters of Lake Michigan showed a particularly high ratio of alcohol to chloroform eluates. Data for monthly samples indicated that this ratio fluctuated seasonally. The periodicity of the fluctuations was similar to those of lake levels and water temperatures.

INTRODUCTION

The U. S. Bureau of Commercial Fisheries has initiated a study of the microorganic compounds present in waters of the Great Lakes, for two reasons. First, this research is pertinent to certain phases of the sea lamprey control program (Applegate et al. 1961), and second, basic data could be obtained that would be of value in research on pollutional and limnological characteristics of natural waters. The distribution and concentrations of particular compounds, such as pesticides and organic nutrients, are matters of national concern (Middleton 1961). The extremely low concentrations in which these compounds sometimes occur make them difficult to detect by ordinary chemical analysis of water samples. These concentrations are often expressed in parts per billion (ppb) by weight. One method by which the substances can be concentrated for subsequent analysis is adsorption onto activated carbon (Middleton, Rosen, and Burttschell 1959). Unfortunately, these and similar studies have not clearly resolved questions regarding qualitative and quantitative aspects of the adsorption and subsequent recovery of specific organic compounds. During the study reported in this paper, the types and amounts of materials adsorbed have been found to vary among samples taken both along the shores and in the open waters of certain of the Great Lakes; seasonal differences also have been observed.

EQUIPMENT AND METHODS

The sampling and laboratory procedures basically were those described by (Middleton et al. 1959). A typical sampling unit contained 400 to 600 grams of activated carbon (Nuchar C-190, 30 mesh) supported on a wire screen in a glass tube that is 3 inches in diameter and 18 inches long. Approximately 5,000 gallons of water were passed through this filter at a rate of 0.25 to 0.5 gal/min/sq ft. A prefilter, packed with sand, was usually connected in series ahead of the carbon filter to remove gross material.

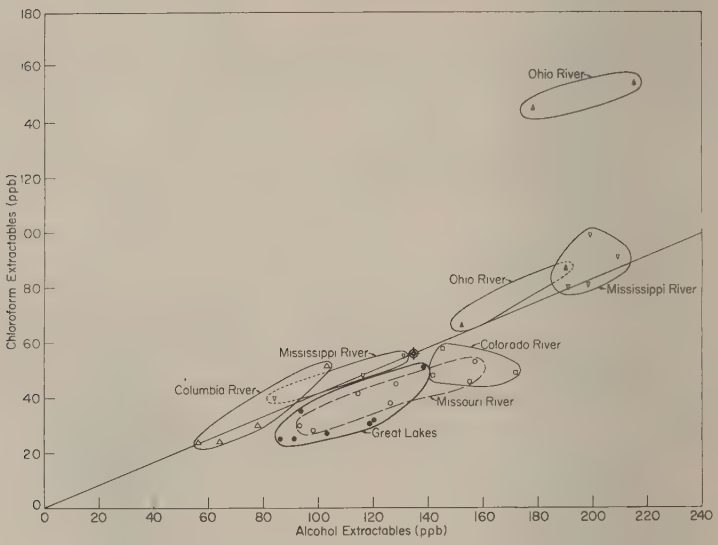

Fig. 1. Alcohol-chloroform eluates for selected drainage basins.

Following a sampling cycle, the carbon was removed, dried, and placed in a 3-liter Soxhlet extractor (Corning No. 3885). The organic adsorbate was eluted from the carbon, first with chloroform and then with ethyl alcohol. The choice of solvents and the order of their use was based primarily upon the polarity of the adsorbed materials. The eluates were subsequently evaporated to dryness and weighed. A determination of residues in the fresh solvents (ACS grade) was also made as a control.

SIGNIFICANCE OF ELUATE DATA

An initial evaluation of the eluate data is possible without prior chemical fractionation of the eluates by an involved analytical scheme. The United States Public Health Service (USPHS) has been reporting annually the data that they are collecting through their Water Quality Network program. About 70% of data reported through September 1961 (USPHS 1957-61) from surface-water sampling stations located all over the united States, have been classified roughly by drainage basins in the present paper (Fig. 1). Plotted points for each sampling station were obtained by averaging all of the available USPHS data from each individual station. The ratio of alcohol to chloroform eluates (A/C) indicates general water quality. The A/C ratio is large in a water containing a high proportion of natural organic matter relative to industrial pollutants. In the Great Lakes region, the average A/C value is above 3 but individual values have ranged from below 1 to above 10. The summation of both coordinate values for a given point is the total amount of organic solutes present in the water. It will be observed that the plots permit separation of data from the different drainage basins. In the present paper, attention is centered upon the Great Lakes. An alcohol-chloroform eluate plot separating the water quality at four of the USPHS stations with respect to pollutional contents is shown in Figure 2. The envelopes were first drawn to enclose individual data points for a particular station; the values of these points were then

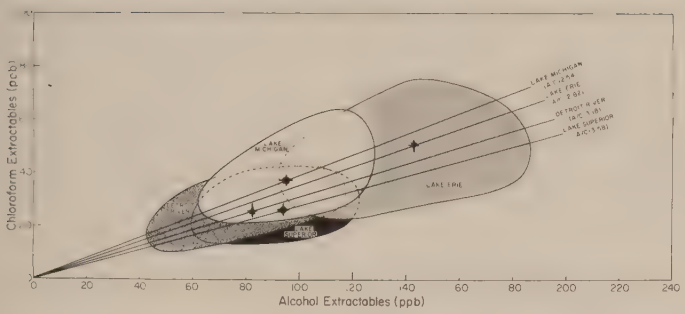

Fig. 2. Alcohol-chloroform eluates for selected sampling stations in the Great Lakes region.

veraged and that value plotted as a single point. The slope of a line passing hrough the origin and this point represents the average A/C ratio for water amples collected at the station whose data are enclosed in the envelope. Conceivably, the pollutional contents of waters from two distinct locations could be differenetiated quantitatively by the A/C ratios for their eluates. Data collected n our own sampling by the M/V *Cisco* from the open water of Lake Michigan luring the summer of 1961 are compared with published USPHS data from two hore sampling stations at Gary, Indiana, and Milwaukee, Wisconsin (Fig. 3). The particularly high alcohol eluate of the limnetic water of Lake Michigan ndicates that the open lake contained a large amount of natural organic compounds. These substances may be different from those found in water sampled ear the shore.

Data from the USPHS sampling station at the Buffalo, New York, water ntake (USPHS 1957-61) showed seasonal fluctuations in the A/C ratio. Other JSPHS data for various stations in the Great Lakes region fluctuated similarly. This seasonal variation was not observed in data of the present research for vater samples taken at the shore sampling station at Hammond Bay, Michigan Fig. 4). This lack of seasonal fluctuation may be due to abrupt changes in vater quality since Hammond Bay receives varying proportions of waters from Lakes Michigan and Superior depending upon wind direction and lake currents. A periodic plot of four quantities: the chloroform eluate (USPHS 1957-61), the A/C ratio, the lake temperature (USPHS 1957-61), and the lake elevation[1] indicates some interesting relationships among these variables (Fig. 5). The quantity of chloroform eluate appears to follow the cyclic rise and fall of the lake elevation. The A/C ratio described a similar curve. Several possible

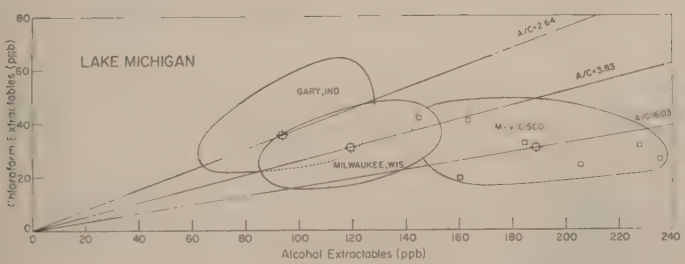

Fig. 3. Alcohol-chloroform eluates for Lake Michigan, shore and open-lake samples.

[1] Lake Survey, U. S. Army Corps of Engineers, monthly bulletins.

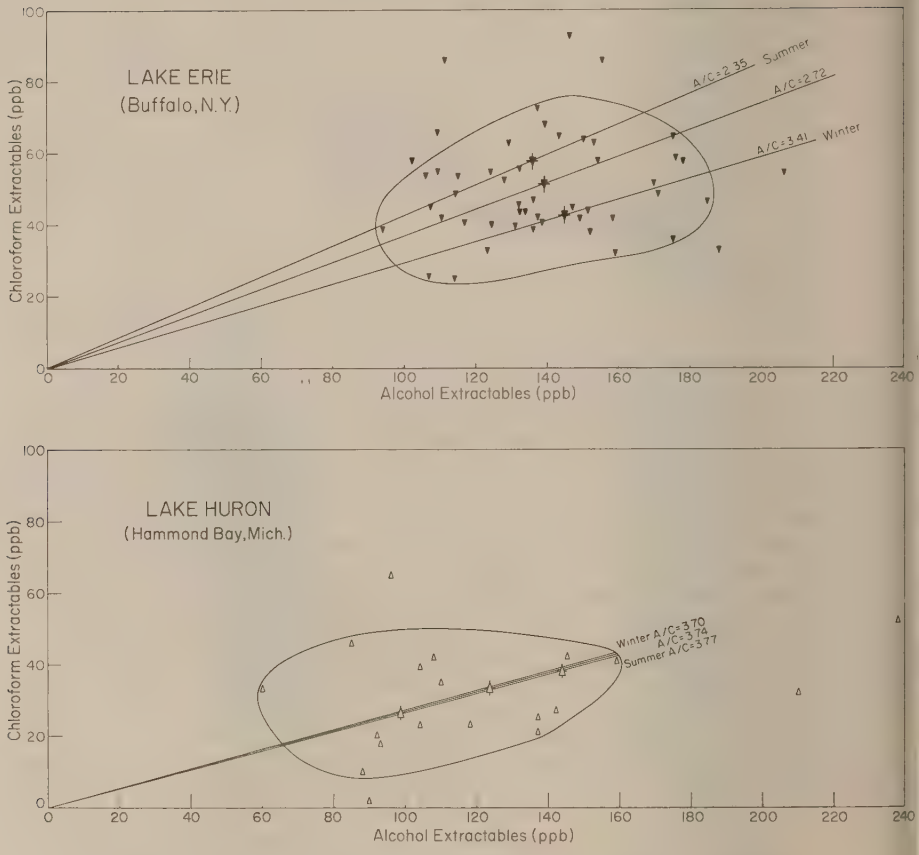

Fig. 4. Alcohol-chloroform eluates, showing seasonal fluctuations.

interpretations are suggested. It would seem that any increase in lake volume would tend to dilute and consequently lower the concentrations of compounds soluble in chloroform, but the opposite effect was observed. Two possible explanations suggest themselves. First, the runoff may have contained large quantities of materials soluble in chloroform. These compounds could be hydrocarbons accumulated on the watershed from many sources. The second explanation is based on the facts that seasonal changes in temperature closely follow fluctuations in lake level and that the adsorption of organic materials onto activated carbon is significantly affected by temperature (Weber and Morris 1963). The plots show that the lake temperatures lag behind the chloroform eluate by approximately 2 months but exhibit the same periodicity. This behavior of the data suggests that more organic material may be adsorbed on an activated-carbon filter when the sampling is carried out in warmer water. It has been demonstrated only recently that the rate of adsorption of alkyl benzene sulfonates is strongly affected by temperature (Weber and Morris 1963). For these reasons, laboratory tests are needed to determine detailed qualitative, quantitative, and rate effects of temperature on the adsorption by activated carbon of specific organic compounds present in natural waters. In addition to temperature, chemical factors also can affect the A/C ratios calculated from data obtained by the activated-carbon technique.

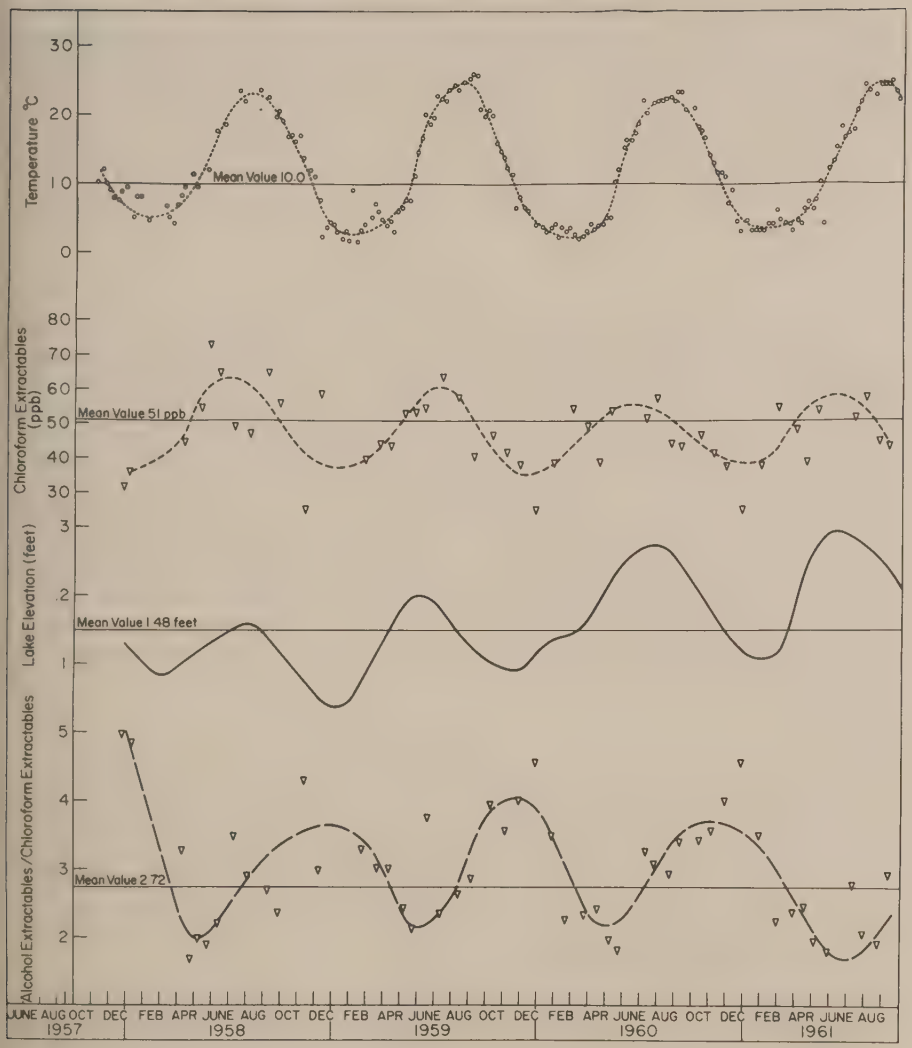

Fig. 5. Cyclic behavior of chloroform eluates, A/C ratio, lake temperature, and lake elevation, Lake Erie.

Broadly speaking, chloroform removes compounds of a hydrocarbon nature and alcohol removes those of a more polar character. Specific organic compounds occurring in each eluate could be chlorinated insecticides in the former and alkyl benzene sulfonates in the latter. No sharp demarcation exists between the composition of the two eluates, however, since both contain mixtures of organic compounds of graded polarity. The degree of adsorption is known to vary with the particular compound under study, its concentration in the sampled water, and with the pH and temperatures of the sampled water. Furthermore, a particular solvent may not elute all of the material previously adsorbed and again, the adsorbed compounds could react chemically while present on the carbon.

If the test for specific organic chemicals in natural water through preliminary adsorption on activated carbon is to become trustworthy, much more information must be obtained. This information should include the efficiency with which specific organic chemicals are recovered from natural waters. This efficiency is probably affected by many factors such as the pH and temperature of the water, the kind of carbon used for adsorption, etc. Some data of this kind are presently available; until more are published, the results of the procedure and of the conclusions based upon it must be interpreted with caution.

SUMMARY

When the organic content of natural waters is determined by adsorption onto activated carbon, the compounds are often separated arbitrarily into those subsequently eluted by chloroform and by ethyl alcohol. The relative concentrations of these two eluates could reflect the water quality in different bodies of water. The character of the eluates can be expected to vary greatly depending upon whether the water is sampled near shore or in the open lake. Furthermore, the rates at which dissolved organic compounds are adsorbed depends upon the water temperature. Thus, the quantitation of the concentrations of organic compounds in natural waters by adsorption on activated carbon requires further examination of the sampling and analytical variables before dependable results can be obtained. Only tentative conclusions can be drawn at the present time, therefore, concerning water quality when the decisions are based upon data acquired by adsorption of organic compounds onto activated carbon.

REFERENCES

APPLEGATE, V. C., J. H. HOWELL, J. W. MOFFETT, B. G. H. JOHNSON, and M. A. SMITH. 1961. Use of 3-trifluormethyl-4-nitrophenol as a selective sea lamprey larvicide. Great Lakes Fishery Commission, Tech. Rep. No. 1, 35 pp.

MIDDLETON, F. M. 1961. Detection and measurement of organic chemicals in water and waste. Water Quality Measurement and Instrumentation, Proc. 1960 seminar at Cincinnati, Ohio. U.S. Public Health Service, SEC TR W61-2, pp. 50-54.

_____, A. A. ROSEN, and R. H. BURTTSCHELL. 1959. Manual for the recovery and identification of organic chemicals in water. Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, 52 pp.

U. S. PUBLIC HEALTH SERVICE. 1957-61. National water quality network. Annual compilation of data. Public Health Service Pub. No. 663., Washington, D.C.

WEBER, W. J., and J. C. MORRIS. 1963. Kinetics of adsorption on carbon from solution. J. San. Eng. Div., A.S.C.E. 89, No. SA2, Proc. paper No. 3483, pp. 31-59.

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THE EFFECT OF SALINITY ON THE TEMPERATURE TOLERANCE OF EGGS AND LARVAE OF SOME LAMELLIBRANCH MOLLUSKS. Harry C. Davis, U.S. Bureau of Commercial Fisheries Biological Laboratory, Milford, Connecticut.

Much of the work on tolerances of lamellibranch eggs and larvae to environmental factors has involved only one variable. A study of the effect of temperature on the survival and growth of larvae of the hard clam (Mercenaria mercenaria) and American oyster (Crassostrea virginica) has shown, however, that the rate of growth of these larvae at different temperatures was critically affected by the type of food organisms available. Both clam and oyster larvae were able to utilize naked chrysophytes, such as Monochrysis lutheri, Isochrysis galbana and Dicrateria sp., and show significant growth, at lower temperatures than those at which chlorophytes, such as Chlorella sp., which have cell walls, could be utilized. This implies that the enzyme systems required to digest naked flagellates are active at lower temperatures than are the enzyme systems required to digest cell walls.

It is known that the cells of I. galbana and M. lutheri are destroyed by temperatures of 27.5°C. to 30°C. and growth of larvae receiving these foods at such temperatures is, therefore, reduced. Chlorella sp. can tolerate temperatures of 33°C. and the rate of growth of larvae receiving Chlorella sp. continues to increase with each 2.5°C. increase in temperature up to 33°C.

The temperature tolerance of clam and oyster larvae is also significantly affected by salinity. At near optimum salinities these larvae survive and grow over a significantly wider range of temperatures than at salinities near the lower limits of their tolerance. In this series of experiments we have determined the temperature tolerances of clam and oyster larvae at a series of decreased salinities.

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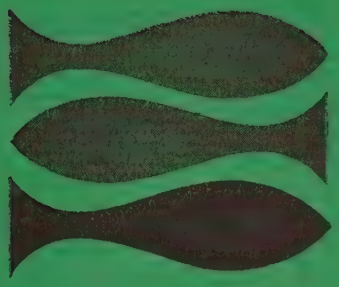

INTERNATIONAL NORTH PACIFIC FISHERIES COMMISSION

BULLETIN NUMBER 13

SALMON OF THE NORTH PACIFIC OCEAN
PART II

REVIEW OF OCEANOGRAPHY OF THE SUBARCTIC PACIFIC REGION

by A.J. Dodimead, F. Favorite and T. Hirano

VANCOUVER, CANADA, 1963

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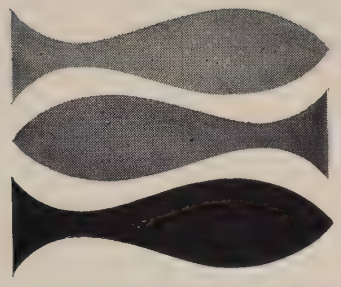

INTERNATIONAL NORTH PACIFIC FISHERIES COMMISSION

Established by Convention between Canada, Japan and the United States for the Conservation of the Fisheries Resources of the North Pacific Ocean

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PREFACE

In 1955 the International North Pacific Fisheries Commission began an extensive program of scientific research on the high seas of the North Pacific Ocean. The program, which continues to the present time, is executed by research organizations of the countries which established the Commission—Canada, Japan and the United States. Principal attention is directed to salmon, genus *Oncorhynchus*, as required by the Protocol to the North Pacific Convention.

This bulletin contains the first jointly-written report of research results to be published by the Commission. It describes the oceanography of the Subarctic Pacific Region, in which salmon spend the marine portion of their existence. The bulletin forms Part II of a comprehensive report on North Pacific salmon, which is being prepared and published by the Commission. Part I of the report appears in Bulletin 12 of the Commission; Part I presents historical statistics of salmon catches and contains an introduction describing the nine separate parts which are planned for the comprehensive report.

Prior to their publication in this bulletin series, research reports have first received the approval of three editorial referees, following which they have been approved for publication by the members of the Commission. At the present time the editorial referees are Messrs. Tasuku Hanaoka for Japan, Donald L. McKernan for the United States and A.W.H. Needler for Canada. Bulletins of the Commission are published separately in English and Japanese. The original language of each paper is indicated and accuracy of translation is the responsibility of the Secretariat.

The various parts of the report on salmon of the North Pacific Ocean may be published out of order; each part will be published as it is completed and receives the approval of the referees and the Commission.

ROY I. JACKSON,
Executive Director.

REVIEW OF OCEANOGRAPHY OF THE SUBARCTIC PACIFIC REGION

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October 1, 1962

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FOREWORD

The International North Pacific Fisheries Commission (INPFC), whose three member nations are

Canada, Japan and the United States of America, was established under the International Convention for the High Seas Fisheries of the North Pacific Ocean in 1953 for the purpose of promoting and coordinating scientific studies necessary to ascertain the conservation measures required to secure the maximum sustained productivity of fisheries of common interest to the members.

One of the immediate tasks assigned to the Commission was " as expeditiously as practical, investigate the waters of the Convention area to determine if there are areas in which salmon (genus *Oncorhynchus*) originating in the rivers of Canada and of the United States of America intermingle with salmon originating in the rivers of Asia. If such areas are found the Commission shall conduct suitable studies to determine a line or lines which best divide salmon of Asiatic origin and salmon of Canadian and United States of America origin " (fully stated in the Protocol of the Convention).

Realizing the importance of the environment, the Standing Committee on Biology and Research recommended oceanography as a possible aid to an understanding of salmon distribution and their movements. Briefly, the basic oceanographic requirements or problems were to determine the characteristics of the environment or region in which salmon are known to live; relate the extent of the environment to the pattern of currents and water structure; observe and recognize seasonal variations in this environment; and determine mechanisms that could account for the observed conditions and factors that cause changes. Presumably, a thorough understanding of these would ultimately lead to a prediction of the marine environment from limited or special oceanographic observations.

At the beginning of the INPFC investigations, national interests permitted an easy division of effort to solve the above problems. Both in operational and research work, the division of effort was made into three broad areas within the Subarctic Pacific Region; western Subarctic (Japan), central Subarctic (United States of America) and eastern Subarctic (Canada). No rigid boundaries were imposed and, in fact, considerable overlap sometimes occurred. This was necessary in order to completely define conditions in these specific areas. Then too, it became evident that a consideration of the whole Region was essential in order to have an appreciation of the continuity or lack of continuity of properties throughout the Region. This approach was developed but was only possible because the data were processed quickly and exchanged freely, often in prepublished form. This quick exchange of data, from one to eight months after completion of a cruise, was a major accomplishment, especially during the early INPFC work when modern equipment such as salinometers and data processing machines did not exist or were not readily available.

Oceanographic observations at sea were generally made in a similar manner by the several agencies, but the analyses of data often proceeded in different directions. This is understandable due to the three-dimensional aspects of the ocean, and the many methods available for the presentation of data. As a result of the different but logical approaches by various authors, it was sometimes difficult to compare particular boundaries or identifying characteristics of the water masses and their movements.

From investigations under the research programs of the INPFC and other agencies, considerable knowledge of the oceanographic features, their seasonal and yearly variations, and mechanisms in the three broad areas and, finally, in the whole Region was accumulated.

In this report, fragmentary information from research conducted prior to the commencement of the INPFC has been summarized. This information and the knowledge obtained from research conducted by the Commission has been synthesized into a presentation of the structure of the water within the Subarctic Pacific Region and a discussion of some of the mechanisms and processes that establish or alter the structure. The dominant features of the structure are used to show the distribution of properties during the years 1955 through 1959. From these distributions specific domains have been identified, the extent and position of which denote the major changes of conditions during the years considered.

I. SUBARCTIC PACIFIC REGION

There have been many studies in which various methods and parameters have been used to define the geographical extent of what is commonly known as the Subarctic Pacific Region. The purpose here is to review some of these studies, and to arrive at some distinct oceanographic feature or parameter which is easily recognized and will adequately define the southern limit of this Region throughout the North Pacific.

Sverdrup *et al.* (1942), using temperature-salinity (T-S) diagrams, defined a Subarctic Water mass " which is characterized in about lat. 50°N. by a average temperature between 2°C. and 4°C. and by a salinity which at the surface may be as low as 32.00‰ but increases to approximately 34.00‰ at a depth of a few hundred metres and below that depth increases

wly to about 34.65‰ at the bottom". They sug-sted that this water mass occurred only north of . 45°N., but generalized the definition to include ter approaching the characteristics of Eastern cific Water. Figure 1 shows representative T-S rves of these two water masses.

Fleming (1955) in his review and bibliography of e northern Pacific identified regions and zones ich were based principally on general oceanographic aracteristics and flow of the surface waters. Al-ough specific regions and zones were delineated ig. 2) and are coincident with some of the domains entified in this report, the boundaries presented were t specifically defined.

In the western part of the North Pacific, off the coast Japan, considerable effort has been directed to udies of the narrow frontal zone at the confluence of yashio (cold) and Kuroshio (warm) systems (Uda, 935, 1938, 1949, 1951, 1955; Ichiye, 1955; Kawaii, 955; Watanabe, 1955; Fukuoka, 1955; Masuzawa, 954, 1955a, b, 1956, 1957). As a result of these vestigations various terms originated; Oyashio ront, Kuroshio Front, Polar Front, Polar Frontal one and Subarctic convergence. Many parameters ere used to distinguish these systems and to show eir geographical variations. For example, Uda 1935) identified the Oyashio system, which he called ubarctic Water, by the presence of a dichothermal mperature (minimum temperature at depth). Others sed the depth of particular isotherms (Masuzawa, 955b) or a surface isotherm, 15°C. (Fukuoka, 1955), define water masses or regions.

In the central North Pacific southward of the Aleu-ian Islands, Favorite and Hanavan (1960), utilizing emperature-salinity and oxygen-salinity curves and ater structure, defined Subarctic, Transition and Central Pacific boundaries.

Tully and Dodimead (1957), utilizing data in the ortheast Pacific, identified Subarctic and Subtropic Waters. They showed that the principal differences ere in the properties and structure of the upper ayers. Those in the deep waters, within small limits, ere similar through the Subtropic and Subarctic Regions of the northern Pacific. Dodimead (1961a), tilizing this concept of structure, defined Subtropic, Transition and Subarctic Waters from the salinity tructure in data from all parts of the northern Pacific. In Subarctic Water, the salinity structure had a dis-tinct halocline (left curve, Fig. 1). In Transition Water, the halocline was not so distinct and the struc-ture below the halocline contained a salinity minimum. In Subtropic Water no halocline was present and the resulting T-S curve is similar to that of Eastern Pacific Water (right curve, Fig. 1). These structures are shown and discussed in Section IV, A.

In all these studies, most of the definitions have specified boundaries that are nearly coincident in the ocean, within the limitations of the data, and are probably equally applicable to define the limits of regions. However, not all the methods have been applied from shore to shore across the Pacific, nor are all the parameters easily identified beyond the areas of original applications.

A feature that seems to persist across the North Pacific in summer is an anomalous isohaline structure which occurs, in the oceanic area, beyond coastal waters, at about lat. 42°N. It is identified by the almost vertical isohaline of 34.0‰ which extends from the surface to a depth of about 200 to 400 metres. The feature becomes less distinct in the eastern North Pacific where more dilute surface waters are encountered, but below these waters the structure can be identified. This structure is apparent in all meridional sections as shown along long. 155°E., 175°E. and 160°W. for summer 1958 (Fig. 3). Recently Favorite *et al.* (1962) have shown that this feature of structure exists in the central North Pacific (along long. 175°W.) during winter at about the same latitude.

The isohaline structure, denoted by the 34.0‰ isohaline, is considered to be a boundary separating two distinct Regions, Subarctic and Subtropic. Using this interpretation, the previously discussed Transition Water is considered to be part of the Subarctic water mass. The position of this boundary is nearly coincident with the position where precipitation equals evaporation (Fig. 6) (Jacobs, 1951). These processes along with differential local heating have produced water structures that have distinct characteristics to the northward and southward of approximately lat. 42°N.

North of the boundary, in the Subarctic Region, the salinity is a minimum at the surface and increases with depth. The water column is characterized by a permanent halocline between approximately 100 and 200 metres depth above which a thermocline develops in summer and vanishes in winter. Thus, the temperature structure only contributes to the stability of the water column in summer, while in winter stability of the water column is entirely dependent upon the salinity gradient (halocline).

South of the boundary, in the Subtropic Region, the salinity is a maximum at the surface and decreases to a distinct minimum below 500 metres depth, but the water column is stable. The salinity at the surface is

a maximum due to excess evaporation, and the stability of the water column depends on the temperature structure. The magnitude and depth of the thermocline varies throughout the year, but it does not vanish.

It is possible that changes in wind stress and transports could cause the position of the boundary to meander. Evidence from data collected in 1955, 1958 and 1962 indicates that its position is relatively constant (between lat. 40°N. and 42°N.) in the central North Pacific. The location of the boundary shown in Figure 3 is sufficiently representative for our purposes. This boundary is used consistently throughout this paper and it is considered to be the southern limit of salmon.

II. GEOGRAPHY AND CLIMATE

Figure 4 shows the Subarctic Region as defined in this paper and all geographical terms used.

A. Bathymetry

Figure 5, adapted from the NORPAC Atlas (Oceanic Observations of the Pacific: 1955, 1960a), shows the general bathymetry (in metres) of the northern Pacific[1]. The greatest depths, those exceeding 4000 metres, are found in the deep trenches south of the Aleutian Islands and east of the Kuril Islands. A substantial part of the Region (excluding Bering and Okhotsk Seas) consists essentially of a broad abyssal plain more than 4000 metres in depth, with numerous submarine mountains (seamounts) which rise to within about 700 metres of the surface. The greatest number of these are present in the Gulf of Alaska.

The Aleutian Islands, and the shallow passages through them, limit the exchange of water between the Pacific and Bering Sea. Only Amchitka Pass (long. 179°W.) is deep enough to allow exchange of waters at depths of 1000 metres. Greater depths occur at the end of the Aleutian ridge between the Near and Komandorski Islands.

Bering Strait, 31 miles wide and having a maximum depth of 90 metres, provides a limited access for the exchange of shallow waters between the Bering Sea and the Polar Basin.

Along the Kuril Island chain only two passages exceed 1000 metres depth. Thus, the exchange of waters between the Okhotsk Sea and Pacific Ocean is restricted.

[1] Recently the U.S. Hydrographic Office has published an excellent series of charts of the depths of the World's oceans of which charts H. O. Misc. 15254–5 and 6 show the bathymetry of the North Pacific Ocean.

The seaward extent of the continental shelf areas usually denoted by the 200 metre contour lin Generally there is an abrupt slope at the outer edg of the continental shelf. As a result the 200 met and 1000 metre contour lines lie very close to one ar other in this small-scale chart. Therefore, the sea ward extent of the continental shelf areas can b roughly denoted by the 1000 metre contour line.

The continental shelf has its widest expanse in th eastern and northern Bering Sea. This area is ex tremely shallow, possessing average depths of abou 60 metres. Also, depths of less than 130 metres ar found in an anomalous ridge extending in a northwes direction north of the Aleutian Islands at long. 180° In the Okhotsk Sea the continental shelf is relativel extensive, and only in the southeastern portion d depths exceed 2000 metres.

B. Climatology

1. *Precipitation.* Jacobs (1951) has shown the ne difference between precipitation and evaporation i the North Pacific Ocean. The mean values in winte in summer, and throughout the year are shown i Figure 6. North of about lat. 40°N. precipitatio exceeds evaporation, and southward evaporation pre dominates (bottom plate, Fig. 6). As noted in th previous section, the boundary where precipitatio equals evaporation generally coincides with th boundary between the Subarctic and Subtropi Regions; thus, the Subarctic is a region of net dilu tion.

2. *Winds.* The mean sea level pressure and pre vailing winds during winter (December–March) ar shown in Figure 7. In general, the Subarctic is unde the influence of a barometric low pressure cell (Aleu tian Low) centered in the Bering Sea near the Aleu tian Islands. Coincident with this, two high pressur cells (Siberian and North American Arctic High occur. Under the influence of this barometric pres sure distribution, the predominant winds in winte are generally westerly; they blow from the northwes in the western part of the Region, gradually backin through southwest on the eastern side. In the north ern part of the Gulf of Alaska, easterly winds prevail.

The corresponding charts of pressure and wind dis tributions for summer (June–August) are shown i Figure 8. In early summer, the Aleutian Low be comes much less intense and the North Pacific High centered between about lat. 30°N. and 40°N., become predominant. The prevailing westerlies of the winte months are then replaced by predominantly south o southwest winds. These warm southerly winds caus extensive " advection " fogs during passage over th

waters near Kamchatka and the Aleutian Islands. the eastern side of the Subarctic (near the Canadi- and U.S. coasts) the prevailing summer winds v from the northwest. Generally light, variable ds occur in the Gulf of Alaska at this time.

ecently, Fofonoff (1960 a, b, c, d, e; 1961) has ented the monthly and annual mean pressure dis- utions for the years 1955 through 1960. These a reflect the marked variations in the strength and nt of the pressure distributions that occurred dur- this period. The annual mean sea level pressure ibutions for the period of this report, 1955 through 9, are presented in Figure 9.

Sea ice. In the northern Bering Sea, ice usually ns in October and spreads rapidly southward; th maximum extent usually occurs in February of ch year (Fig. 4). During the winter, ice is present oughout the northern half of the Bering Sea and ers the entire Okhotsk Sea. By July, it is found y in the Gulf of Anadyr and in Bering Strait. In ly and August, all ice disappears in these areas and en water is present northward of Bering Strait. The S. Hydrographic Office has periodically issued re- ts of ice conditions in the Arctic which include nthly conditions in the eastern and northern ring Sea.

Incident energy, cloud cover and insolation. Figure 1 (Tully and Dodimead, 1957) shows the annual cle of incident energy (gram cal/cm²/day), assuming n cloud cover, from lat. 35°N. to 60°N. During mmer, between lat. 40°N. and 60°N., the incident ergy is nearly constant; a gradient develops in autumn, reaches a maximum in winter, and degener- es in spring. Mean values for summer (June–August) and winter (December–February) are also shown in the diagram and range from about 800 to 90 and from 100 to 400, respectively.

Cloud cover absorbs 7.1% of the incident energy f every tenth of the sky obscured. Applying this rection to the average cloud cover during winter d summer, the incident energy at the sea surface f these periods has been computed (Fig. 11). The ulting distributions of energy correspond closely th the distributions of winter and summer surface therms.

Sea surface temperature. A number of sea surface mperature charts, generally compiled from ships' ords, are available for various periods. The Japa- se Meteorological Agency publishes 10-day reports sea surface temperatures between lat. 10°N. and °N. and west of long. 180°. Since 1957 the U.S. sh and Wildlife Service, Bureau of Commercial Fisheries Biological Laboratory, San Diego, California (originally published by the Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii), has been publishing monthly sea surface temperature charts of the North Pacific east of long. 180°. These publications also compare current monthly data to those of the same period in the previous year, and to a long term mean. Recently, a Canadian Oceanographic Information Service (Giovando, 1962) has been established in Esquimalt, B. C. This Service, in addition to publishing weekly sea surface temperature data in the eastern Subarctic Region, publishes other weekly charts such as depth of the seasonal thermocline, magnitude of the thermocline and temperature at the bottom of the thermocline, from daily series of bathythermograph data radioed to the Information Centre.

The Bureau of Commercial Fisheries Biological Laboratory, Stanford, California, has commenced issuing average monthly charts of the northern Pacific which utilize all available data and in which questionable data have been eliminated or corrected. Charts of average monthly sea surface temperatures (°C.) during the year 1956 are produced here to show the monthly ranges of temperature in the Subarctic (Fig. 12 a, b, c, d) (Saur and Eber, 1962). The configuration of the isotherms is generally similar for each month. The waters are coldest in late winter at the end of the cooling season (February and March) and warmest in late summer, at the end of the heating season (August and September). Near the southern limit of the Subarctic a marked north-south gradient persists which is generally called the Polar Front. The annual range over most of the Region is of the order of 6°C. to 9°C. The corresponding charts from other years show the same features; however, the absolute values vary in some localities.

III. HISTORY OF OCEANOGRAPHIC INVESTIGATIONS

The International North Pacific Fisheries Commission was formed in 1953, but it was not until 1955 that any major oceanographic program could be initiated in the Subarctic Pacific Region. Although that year's program was a result of expeditions organized by the NORPAC Committee, oceanographic programs during the following years were maintained and expanded in keeping with the increased exploratory fishing, tagging and research studies conducted to determine the oceanic distribution of salmon. For this review it is convenient to divide the oceanographic investigations and research works concerning the Subarctic into two periods; prior to 1955, and since 1955. The

important sources of data and reference material prior to 1955 are summarized and some of the research works that deal with water structure (characteristics of properties with depth) and circulation are briefly reviewed. Then, a brief outline of the scope and the purpose of the investigations since 1955 is presented, and the data sources and oceanographic coverage during 1955 through 1959 are shown. It has been primarily these data that have made it possible to deduce the features of structures, mechanisms and domains in the Subarctic Region.

A. Investigations Prior to 1955

Bibliographies of oceanographic cruises and research works during this period have been compiled by various authors and agencies. An early listing of oceanographic data was given by Vaughan (1937). Grier (1941) compiled the important papers dealing with oceanographic and biological studies in the North Pacific to 1938. Following this the U. S. Navy Hydrographic Office (1953) compiled references dealing with "Physical Oceanography of the Western Pacific Ocean". The Japan Agricultural Technical Association (1954) published available data and cruise plans in the northern Pacific Ocean (north of lat. 40°N.) by years for the period 1887–1954. Love (1956) listed the available oceanographic data, primarily that collected between 1916 and 1954, in the portion of the North Pacific Ocean extending from the west coast of North America to long. 150°W. between lat. 20°N. and 50°N.; and Saur (1958), using much the same format, listed meteorological and oceanographic reports of time-series data.

Recently Scripps Institution of Oceanography has been compiling data from the Pacific Ocean. These data are being published by the University of California Press in "Oceanic Observations of the Pacific". To date, the data from the pre-1949 period, 1949 and 1950 have been published (Scripps Institution of Oceanography, 1961, 1957, 1960).

Reports available for this pre-1955 period show that the cruises and subsequent studies were confined to relatively small portions of the Subarctic; e.g., in portions of the Bering Sea, Gulf of Alaska and off the northern Japanese islands. The far-ranging expeditions usually traversed large areas by single lines of oceanographic stations. As a result, detailed studies of the Subarctic were confined to relatively small areas in the Region. Surface temperature conditions and surface drift compiled from ships' records such as those published by Schott (1935); U.S. Department of Agriculture (1938) and the U.S. Hydrographic Office (1944a, b, and 1947) and the Pilot Charts (U.S. Hydrographic Office) were informative but of limit use because they represented average conditions a only showed gross features of properties at the surfa A synoptic picture of the oceanographic properties depth across the Pacific was not available.

Of the few publications during this period whi relate to the entire Subarctic, the most outstanding that by Sverdrup *et al.* (1942) who reviewed most the data and research work prior to 1940. They d fined specific water masses (as identified by T-S re tionships), current systems and transports. In a v view of the other investigations, it is convenient divide the Region into four parts—(1) Bering S (2) Western Subarctic, (3) Central Subarctic (south the Aleutian Islands) and (4) Eastern Subarct These areas are shown in Figure 13, which also sho the major current systems recognized prior to 195

1. *Bering Sea.* The first work of interest is that Ratmanoff (1937). He showed that most of the wat from the Pacific entered the Bering Sea between t Komandorski and Near Islands, and flowed in a nort eastward direction through the Bering Sea. A lar part of the western edge of this stream eddied ba toward Kamchatka forming a counterclockwise gy and produced a south-flowing current along the sho (see Fig. 14). In the smaller passes between the Ale tian Islands, a northward movement of water w reported surging to the westward in the Bering S This flow was believed to be part of a large clockw eddy characteristic of the southern portion of t Bering Sea.

Following this work, Barnes and Thompson (193 reported on the observations made during the ye 1933 and 1934 from U.S.S. *Gannet* and U.S. C.G. *Chelan.* They noted that surface waters in the Paci along the southern side of the Aleutian Islands, and a distance of 40 miles offshore, moved northward wi velocities sometimes exceeding 0.3 knots (7 miles/da and that in some cases this northward flow was a companied by a slight eastward component. T greater quantity of water apparently flowed nor into the deeper passes west of Tanaga Island (lor 178°W.). Water in Bering Sea just north of t Islands flowed toward the east and north, with ma mum velocities of about 0.1 to 0.2 knots (2.5 to 5 mil day). Subsurface currents were similar in directi to the surface currents, but in general, velocities d creased with depth and became negligible or sm at a depth of 1000 metres. Goodman *et al.* (194 summarized the circulation from these earlier wo (Fig. 14).

During the years 1938 through 1941, oceanograp

vations were made from the U.S. C.G.T. *Redwing* e eastern Bering Sea and Bristol Bay (Favorite Pederson, 1959, and Favorite *et al.*, 1961). A nary of the data is presented in Appendix I.

Fond and Pritchard (1952) reporting on the ts of the 1947 cruise of the U.S.S. *Nereus* in the rn Bering and Chukchi Seas concluded that ern Bering Sea water flowed northward and was fied by water from the rivers along the Alaska and from intrusions of cold high-salinity water the western Bering Sea. This mixture of water ed northward through Bering Strait, principally e surface on the eastern side.

uring July and August 1949, United States and adian oceanographers participated in what can considered a multiple ship survey in Bering and kchi Seas (Saur *et al.*, 1952; 1955). The surface ulation, computed from the 500 metres reference . (Fig. 15) showed the presence of a counterclock- circulation in the southern Bering Sea, opposite to presented by Ratmanoff (1937) or Goodman *et* 1942). The temperature minimum that existed 00 to 150 metres depth was attributed to cooling convection, and sluggish southeastward advection old water across the Bering Sea. Thus, they tioned the existence of the pronounced north- ward current in the central Bering Sea indicated igure 14.

Ishima and Nishizawa (1955) reporting on condi- s in the southern Bering Sea from results of the 3 and 1954 cruises of the *Oshoro Maru* also showed tification of the water column at most stations, bsurface layer of cold water and low salinity at metres depth and a deeper layer of maximum peratures at 300 metres. They also suggested t the cold water layer originated near the Asian st of the Bering Sea and spread over the deeper er of density intruding from the Pacific.

Winter and spring data from the oceanographic veys in the eastern Bering Sea during 1955 (U.S. Navy Hydrographic Office, 1958) conducted aboard U.S. C.G.S. *Northwind* and U.S.S. *Burton Island* vided both representative bathythermograph traces station data. Surface temperatures ranged from .85°C. in the ice pack to 3.4°C. in the open water. ther, the water on the shelf under the ice was erally isothermal at about −1.6°C. and isohaline h values between 31.8 and 32.4‰.

2. *Western Subarctic.* With the exception of oceano- phic cruises aboard the *Carnegie* in 1929 and *Baird* 1953, all data collected in the western Subarctic ve come from Japanese and Russian cruises.

Prior to 1941, Japanese research ships such as *Unyo Maru*, *Shunkotsu Maru*, *Hakuho Maru*, *Soyo Maru* and *Tankai Maru*, were engaged in oceanographic surveys in relation to fisheries. More detailed observations over a more extensive area were made aboard former Japanese naval vessels, such as *Manshu*, *Komahashi*, *Itsukushima*, *Otomari* and *Ryofu Maru*. Data from most of these cruises were not easily accessible until tabulated and published by the Japanese Agricultural Technical Association (1954).

The most intensive oceanographic work during this period was confined to the area off the coast of Japan, particularly at the confluence of the Oyashio and Kuroshio systems. Uda (1959) has presented a syllabus in which most of these early reports are summarized.

Shigematsu (1933), using data collected aboard the *Unyo Maru* and *Manshu* in 1916 and 1917, computed surface currents in the Okhotsk Sea using 400 decibars as a reference level. He reported a southward flow in the central part of the Sea; near the Kuril Islands the flow divided, part turned northward, and the rest flowed into the Pacific contributing to the Oyashio Current. Uda (1934) proposed that water between 40 and 200 metres depth, having temperatures between 0°C. and 0.5°C. and salinities between 32.3 and 33.0‰, originated in the northern part of the Sea and moved southward along the east coast of Sakhalin Island.

In other reports Uda (1935, 1938) pointed out the existence of this cold water layer in the western Subarctic. He discussed the dichothermal (subsurface minimum temperature) and mesothermal (subsurface maximum temperature) layers and suggested a close relationship between the dichothermal layer and the low-salinity water underlying the Kuroshio.

Kishindo (1940 a), utilizing potential temperatures (temperature that a water sample would have if raised adiabatically to the sea surface), concluded that water below 2000 metres in the Okhotsk Sea originated from the Pacific side of the Kuril Islands. He also presented vertical sections of properties through the Pacific from lat. 56°N. to 72°S. (Kishindo, 1940 b). He reported that the water between 2000 and 3000 metres flowed to the southward and below 4000 metres northward and concluded that the deep water originated in the Antarctic Ocean and not in the Okhotsk Sea.

Later Kajiura (1949) utilizing observations made near the Kuril Islands in summer 1942 aboard the *Ryofu Maru* reported that the near-surface water flowed into the Okhotsk Sea through the northern Kuril

Island passes and out through the central passes. He suggested that the currents were generally weak and were influenced by the prevailing winds.

The first extensive work published in the postwar period was by Saito (1952). Presenting a theoretical analysis of lateral and vertical diffusion between water masses, he discussed the use of T-S curves and identified northern and southern upper water; northern and subpolar intermediate water; deep and bottom water. In most instances these water masses were further subdivided. He also discussed the distribution of properties and extent of water masses off the east coast of Japan during August 1943 and April 1945; and suggested that the surface water in the Bering Sea appeared to be isolated from the surface water in the Oyashio system, but that the intermediate water of the Oyashio was formed by a mixture of intermediate water from the Bering Sea, Okhotsk Sea and the area near the Kamchatka Peninsula.

Since the reopening of the high-seas fisheries in 1952, the *Tenyo Maru* and *Oshoro Maru* have been engaged in oceanographic surveys. Watanabe (1954) reported the results of observations from the *Tenyo Maru* in 1952 and 1954, and discussed the short period variations of surface temperatures. He suggested that fog formation in the region was an important factor in influencing oceanographic conditions during summer.

Hirano (1957a, b) using data collected during 1954 aboard *Tenyo Maru* identified a number of water masses and temperature structures as shown in Figure 16 which provided considerable information concerning water masses and the circulation in this part of the Region.

Since 1955, many other reports have been published utilizing data collected prior to 1955. In reports such as Uda (1955), Hirano (1958, 1961), Koto and Fujii (1958), Sugiura (1957) and Kitano (1958), accounts of oceanographic conditions were presented. Briefly summarized, the reports showed that along the southern side of the Aleutian Islands there was a westward current which branched into the Bering Sea through the many inter-island passages; and furthermore, there was a counterclockwise gyre of Subarctic water centered in the vicinity of lat. 50°N., long. 165°E.

3. *Central Subarctic.* The scarcity of reports concerning this area indicates that it had either been neglected or was inaccessible with the existing ships. The work of Goodman *et al.* (1942) has been discussed. Barnes and Thompson (1938) reporting on oceanographic sections near Adak and Tanaga Islands noted that the water in the Bering Sea to a depth of 400 metres was colder, and from 800 to 3000 metres w warmer, than in the Pacific. Oxygen concentrati in the Bering Sea at the surface and at depths of 1 to 800 metres were greater and below 1000 metres w less than in the Pacific. Concentrations in the mi mum oxygen zone were similar in both areas but m than twice as large as minimum concentrations fou near the Washington coast in 1933. However, stati in the Aleutian area extended only 50 miles offsh and represent coastal rather than oceanic conditio

There have been isolated Japanese cruises in t central Subarctic as far back as 1908, but most of t reports of these cruises deal with conditions in t western Subarctic, and have been discussed. Ho ever, in 1952, in conjunction with offshore fishi Japan resumed oceanographic investigations in t central Subarctic. Noting limitations of the d because of the relatively few oceanographic statio Mishima and Nishizawa (1955) discussed ocean graphic conditions southward of the Aleutian Islan during 1953 and 1954. They reported warm wa of low salinity flowing westward along the southe side of the Aleutians which, although gradually d sipated by losses into the Bering Sea, extended as west as long. 165°E. before being completely d sipated. South of this warm water a narrow tong of abnormally cold water, believed to originate in t Gulf of Anadyr, flowed eastward. These moveme were based on the geostrophic currents shown in Figu 17.

4. *Eastern Subarctic.* Early work in this area w undertaken by the International Fisheries Commissi to ascertain the nature, direction and velocity of t currents in the Gulf of Alaska as an aid in the b logical studies of the halibut (McEwen *et al.*, 19 Thompson and Van Cleve, 1936; Thompson *et a* 1936). Oceanographic observations made alo sections from the coast, offshore to the central part the Gulf of Alaska, permitted a calculation of ge strophic currents parallel to the coast (Fig. 18). T strongest flow occurred just off the continental sh and was counterclockwise around the Gulf. T greatest irregularities, both in direction and spe occurred in the waters overlying the continental she " Coastal ", " Intermediate " and " Ocean " wat were defined from values of chlorinity.

Some results of drift bottle experiments, shown Figure 19, indicated the existence of a counterclo wise current around the Gulf, and that this curre transported water into the Bering Sea through t Aleutian passes. Experiments off the North Ame can coast indicated that the eastward flowing wa divided well south of lat. 47°N. in March, and ne

a 50°N. during the summer. This division was ...id to conform to the latitude of separation of ...dual winds with a northerly component and those ...h a southerly component, as calculated from the ...t Charts of the U.S. Hydrographic Office.

...ully (1937) using data from a small area seaward ...he coast of Vancouver Island (approximately 100 ...es) showed the presence of a southeastward current ...ich extended to within 10 miles of the coast.

The next major investigation was carried out by ...odman and Thompson (1940). They used T-S ...tionships to demonstrate the major features in this ...a and identified five water masses. The water ...mediately south of the Aleutian Islands, which flow-...westward, was associated with the Alaska Current ...askan Stream). Southeast of the Stream in the ...tral Gulf of Alaska was found " South Aleutian ...er " within which surface temperatures and saliniti...were fairly constant. To the eastward of this, the ...er which flowed northward past the coast of British ...umbia and southeast Alaska was identified as the "...ashington drift ". Further inshore, the water ...ng the continental shelf was called " Coastal ...er ". Finally, the eastward flow, southward of ...se water masses, was called the " North Pacific ...eam " (West Wind Drift). The existence of clock-...e eddies at the boundaries of these water masses ...s noted.

...lthough considerable data were gathered during ...9 (Scripps Institution of Oceanography, 1957) and ...the following years, there were no further major ...tributions in this area until Doe (1955) published ...e results obtained from cruises covering the " Off-...re " waters of the British Columbia coast during ...0–51. These cruises provided the first good synop-...ti data in the eastern Subarctic. Doe recognized ...e existence of three distinct zones in the water struc-...e. They were identified in the T-S relationships ...l in plots of the properties versus logarithm of the ...th as the surface zone (0–94 m.), halocline (93–...3 m.) and the lower zone. He concluded that the ...e of the halocline was to act as a barrier to the ...sage of water from the lower zone to the surface ...e or vice versa; thus, the temperature at the bot-...h of the surface zone (top of the halocline) could be ...sidered a quasi-conservative property of the sur-...e water mass. Further, the temperature at the top ...the lower zone (bottom of the halocline) could be ...sidered a conservative property of the lower zone. ...e salinity at the bottom of the halocline was ap-...oximately 33.8‰.

Doe also concluded that the currents were weak ...d variable in this area. At individual stations, the direction of currents at different levels was similar to that at the sea surface, but the velocity decreased with depth until at 300 metres it was approximately one-half that at the surface. Further, the general direction of flow suggested by isentropic charts was similar to that indicated by the calculated dynamic topography (geostrophic currents). The water identified by Goodman and Thompson (1940) as " South Aleutian water ", was found immediately westward of the offshore region and was called " mid-gulf water " (Fig. 20). Differences between the conditions observed in the two summers (1950 colder than 1951) were noted, and believed to be related to the position of division of the water flowing from the west. This work laid a sound foundation on which future studies in this area were based.

Prior to 1955 other studies were carried out in the area by the Department of Oceanography, University of Washington. Barnes and Paquette (1954) discussed currents off the coast of Washington. Their conclusions were in general agreement with the previous works, and indicated a region of division well offshore at about lat. 45°N.

Scripps Institution of Oceanography collected data off the west coast of the United States in winter and summer in conjunction with their Marine Life Program conducted for the California Cooperative Oceanic Fisheries Investigations. Most of this work is not of major interest for this review because it was limited to the coastal areas and southern extremity of the eastern Subarctic Region.

B. Investigations Since 1955

Although the oceanographic surveys have been continued to the present time, this review considers only the extensive data collected during 1955 through 1959 by agencies of Canada, Japan and the United States of America. Studies of these data have resulted in significant advances in an understanding of the Subarctic Pacific Region, in particular, an insight into water structure and mechanisms and a more complete understanding of the circulation, both of which have permitted identification of water masses and domains.

The sources of data are given at the end of the report. Most of the individual cruises directly connected with the INPFC and some preliminary results have been described in the annual reports of the International North Pacific Fisheries Commission (1957, 1958, 1959, 1960).

1. *1955.* Although some exploratory fishing operations for the INPFC were made in 1953 and 1954, it was not until 1955 that any appreciable oceano-

graphic work covering the Subarctic was accomplished. The NORPAC expeditions provided the first synoptic oceanographic coverage in the North Pacific Ocean north of lat. 20°N. (Fig. 21). The data are presented in atlas (Oceanic Observations of the Pacific: 1955, 1960a) and tabular form (Oceanic Observations of the Pacific: 1955, 1960 b). Also, observations were made by the Department of Oceanography, University of Washington, from the vessels *Mitkof*, *Paragon* and *John N. Cobb* engaged primarily in exploratory fishing (Favorite and Love, 1957).

2. *1956.* Although the year 1956 fell between the extensive NORPAC expeditions and the subsequent acceleration of oceanographic work during 1957 through 1958 as a result of the International Geophysical Year, good oceanographic coverage was obtained almost exclusively by agencies contributing to the INPFC program (Fig. 22). The figure is somewhat misleading as to the amount of adequate data available for this period. It should be pointed out that except for the data obtained from the *Oshoro Maru*, *Tenyo Maru*, M. V. *Brown Bear* and H.M.C.S. *New Glasgow*, observations deal with bathythermograph observations, with near surface waters, or the depth intervals of sampling were so large that interpolation between depths was difficult or inaccurate.

During 1956 the Canadian group expanded their oceanographic program aboard C.C.G.S. *St. Catharines* occupying Ocean Weather Station " P " (lat. 50°N., long. 145°W.) during alternate six week periods, to include complete oceanographic observations. Bathythermograph observations were maintained on the other vessel, C.C.G.S. *Stonetown*, occupying this station. These and subsequent data from this position made it possible to understand some of the mechanisms associated with the temperature and salinity structures.

3. *1957.* In January, the Canadian program was expanded to include a winter oceanographic cruise in the eastern Subarctic (Fig. 23). This cruise provided information on the winter structure and circulation and eventually permitted a better interpretation of summer conditions.

In summer, an oceanographic group was established within the Bureau of Commercial Fisheries Biological Laboratory, Seattle, which took over the United States oceanographic research in the INPFC previously conducted by the Department of Oceanography, University of Washington. The work was carried out on exploratory fishing vessels, principally in the Bering Sea and in the waters immediately south of the Aleutian Islands. An expansion of oceanographic work aboard these vessels made it possible to give a good assessment of the oceanographic conditions in t area. Data from these cruises when combined w those from Japanese and Canadian surveys maintain continuity of observations across the Subarctic. T resultant coverage which includes various cruises c ducted under the International Geophysical Y (IGY) Program is shown in Figure 24.

4. *1958.* A winter oceanographic survey w carried out in the eastern Subarctic by the Canadi group to monitor the oceanographic conditions in t area and to learn if the circulation was accelera during the winter months near the edge of the c tinental shelf. Also, data from depths greater th 2500 metres were obtained, which are requisite deep current studies. Data were also gathered the Department of Oceanography, University Washington (Fig. 25).

In 1958, realizing the necessity of extensive synop oceanographic coverage in the central area south the Aleutian Islands, which the United States explo tory fishing vessels were unable to obtain independe ly, the Canadian group assisted in obtaining data the central Aleutian area and the Bering Sea; and Bureau of Commercial Fisheries Biological Labo tory, Honolulu, extended their oceanographic obser tions, taken in conjunction with their albacore stud as far north as practicable. These cruises, as well the excellent coverage provided by various Japan agencies in the western Pacific and the work off coast of the United States by the Department Oceanography, University of Washington, provi the best oceanographic coverage ever obtained in Subarctic Region (Fig. 26). Dodimead and Favo (1961) have published an Atlas of these combined da An Atlas of the Japanese Oceanographic Project IGY, 1957 and 1958, has also been published (Natio Committee of IGY, 1960).

5. *1959.* Conditions in the eastern Subarctic w again monitored during the winter period (Fig. 2 These data have been published in atlas form (D mead, 1959).

During summer 1959, the absence of support operations to the southward limited the coverage the central Subarctic (Fig. 28). However, exten cruises by United States and Japanese vessels provi the best coverage to date in the Bering Sea. At same time the Canadian cruises in the eastern S arctic were extended southward. Also, measurem were made to depths of 4000 metres at some statio

6. *Subsequent work.* Although the results of oceanographic programs presented in this report based upon data collected during the cruises 1

ugh 1959, spring and summer surveys are still g made. The data have been or are being pub- ed. Winter data in the eastern Subarctic were n in 1960 and published in atlas form (Dodimead,) and winter data from the central Subarctic were n for the first time in 1962 (Favorite *et al.*, 1962).

IV. STRUCTURE AND MECHANISMS

A. Salinity

The salinity structure is a unique and permanent ture of the Subarctic Pacific Region. Most of the racteristics of the salinity structure and its variations e been described from time-series data at Ocean tion " P " (lat. 50°N., long. 145°W.) by Tabata 61) and Dodimead (1961 a). Mechanisms for this cture and its significance have been proposed by ming (1958), Tully and Barber (1960), and Dodi- ad (1961 a).

The principal features of the salinity structure are parent in Figure 29 which shows a sequence of three ical structures from summer through winter to the t summer at Ocean Station " P ". The permanent tures are (1) an *upper zone* from 0 to about 100 tres depth; (2) a *halocline* in which the salinity reases by about 1‰ in the depth interval from about to 200 metres; and (3) a *lower zone* in which the nity increases gradually but uniformly to about 4‰ at 1000 metres depth. Below this depth the nity increases very gradually to 34.67‰ at 4000 tres.

The bottom of the halocline (or top of the lower e) can be defined with considerable accuracy 0.1‰) by the isohaline surface of salinity=33.8‰. lly and Barber (1960) suggested that the bottom of halocline is the ultimate limit of downward transfer water from the surface and at this level the transfer water is unidirectional upward. They concluded t the lower zone water is entrained into the upper e through the halocline but fresh water is con- ved within the upper zone and halocline; that is, features of a simple estuarine system are present.

The most significant variations in the salinity struc- e occur within the upper zone and are primarily e to seasonal effects. Dodimead (1961a) has scribed these variations from a sequence of salinity uctures at Ocean Station " P " shown in Figure 30. mperature structures are included in the figure cause in this zone both structures are influenced her directly or indirectly by the same seasonal proc- es. For the following discussion it should be noted t the geostrophic flow in the vicinity of Ocean tion " P " is generally zonal, but, more important, slow (2 miles/day). Hence, within the time period considered here, the waters in the area are subjected to climatic conditions similar to those at Ocean Station " P "; thus, they can be regarded as having resided there.

Tabata (1961) has defined the periods of heating, April to September, and cooling, October to March, at Ocean Station " P " (Fig. 31). During the late cooling period, the salinity and temperature structures are isohaline and isothermal from the surface to the top of the halocline, and during the heating period, April to September, a secondary halocline is formed in the upper zone coincident with the thermocline (Fig. 30). Below the secondary halocline the salinity structure instead of being isohaline, as during the cooling period, develops a slight gradient to the top of the main or principal halocline. This latter change in structure can be related to the " entrainment " processes associated with the estuarine mechanism (Tully and Barber, 1960) or possibly vertical eddy diffusion. Either of these processes tend to increase the salinity and create a gradient in this part of the upper zone.

During the early cooling period, October through November, the secondary halocline decays, sinks and eventually vanishes into the permanent halocline. As a result, a relatively shallow isohaline and isothermal layer and a larger halocline (ΔS) is formed. This process continues throughout the cooling period until the waters become homogeneous to an ultimate depth defined in the salinity structure by the top of the halocline. This sequence of events is shown in Figure 32.

The upper zone is established during the period of cooling, and although it undergoes changes, it can be identified throughout the period of heating. It is again re-established during the winter period. This sequence recurs from year to year. Tabata (1961) has discussed the seasonal values of salinity at selected depths of the water at Ocean Station " P " for the two years August 1956 through July 1958. The variations are most marked in the upper zone (0–100 m.) (Figure 33) and are consequences of the growth and decay of the seasonal thermocline which is discussed under Temperature (p. 12). The seasonal thermocline effectively protects the underlying waters from surface effects such as warming and dilution. The excess precipitation during summer accumulates above the thermocline resulting in minimum surface salinities at the end of the heating season. During this time, the salinity of the water below the thermocline is increased by upward transfer (entrainment) of more saline water from the halocline, and the highest salinity values in

the sub-thermocline zone (at and near the bottom of the upper zone, e.g., 100 metres) are found in autumn. Thereafter winter turnover mixes the surface waters to homogeneity down to the depth of the top of the halocline, resulting in a reversal of conditions; the salinities at the surface attain their highest values and salinities at the top of the halocline (approximately 100 metres) attain their lowest values.

In 1953 Tully (1956) showed that the salinity zone structure of a simple estuarine system could be accurately delineated by plotting salinity as a function of the logarithm of the depth. In such a plot the upper and lower limits of the halocline (or transition zone) are characterized by two well defined discontinuities. Since then this method has been used by Doe (1955) and Dodimead (1961 a) to define the features of the salinity structure in the Subarctic. Typical salinity profiles (salinity *vs.* logarithm of the depth) of the zone structure in the northern Pacific are shown in Figure 34. It is evident that the simple zone structure, similar to that at Ocean Station " P ", predominates over nearly all the oceanic part of the Subarctic. This is confirmed in the vertical sections of salinity. The structure is dependent upon surface dilution and the absence of extensive vertical mixing, otherwise modification of the simple 3-zone structure occurs; the halocline expands and its lower limit becomes less distinct. Extreme modified structures occur in the Okhotsk Sea and the island passages (Kuril and Aleutian) (e.g., see Station A, Figure 34).

Figure 35 shows a sequence of salinity structures in the area extending from lat. 50°N. to the Subarctic boundary. The simple 3-zone structure is present, but the halocline and hence upper zone becomes progressively less pronounced southward. Near the boundary an increase in the salinity at the bottom of the halocline occurs (33.8‰ to 34.0‰). In this area, the features of the upper zone become complex and salinity inversions may occur. However, the water column is stable because of the marked temperature gradients.

At the Subarctic boundary the upper zone and halocline vanish.

B. Temperature

Within the Subarctic Region, the temperature structures have marked variations, both seasonally and with locale. The principal features of the temperature structures can be described from data observed at Ocean Station " P " and presented in Figure 36 (zones identified in the salinity structures (Fig. 29) are shown). In summer, there is an isothermal or near isothermal layer, corresponding to the isohaline layer, extending to about 30 metres depth. Belo this layer, a marked thermocline is present whi corresponds in position to the secondary haoclii extending to about 75 metres depth. Below th depth, one of two conditions occurs; either the ten perature of the water decreases continually with dept or increases slightly within the halocline. In bo cases there is a negative gradient in the lower zone

In the winter, the isothermal (and isohaline) lay extends downward to the top of the halocline (appro imately 100 metres depth). Below this level and the halocline there may be a positive or a negati gradient depending on the severity of the coolii during the winter period. The occurrence of the structures and the magnitudes of the gradients a directly related to the amount of surface cooling ar the temperature of the waters in the halocline. I the lower zone, the temperature decreases with dept similar to the summer structures.

Figures 31 and 37 define the annual cycles of heatii and cooling and of temperature structures at Ocea Station " P ". In April, with the advent of the hea ing period, a thermocline is formed. The overlyii waters continue to warm and the thermocline gro until the end of the heating period. The heat is n transferred below the thermocline and a remnant the cold isothermal (isohaline) structure formed durii the previous winter remains. During the coolii period, the surface layer cools and deepens; the the mocline decays, becomes abrupt and sinks. Usual by March it vanishes along with the secondary hal cline.

Tully and Giovando (1962) have illustrated a described the mechanics of this growth and decay the thermocline in the semi-daily bathythermogra observations at Ocean Station " P ". They conclud that in the oceanic areas away from coastal turbulen three dominant processes are involved; heating, co ing, and wind mixing. The mechanics of these pro esses are considered similar in all oceanic areas, d fering only in degree from place to place and time time.

Heating is due mainly to radiant energy from t sun which occurs only during daytime. Cooling due to evaporation, back radiation and conducti of heat from the sea surface, and is continuous day a night. Hence, there is a diurnal cycle of surface hea ing and cooling. During the heating period, Ap to September (Fig. 31), some of the heat gained daytime is retained through the night; hence, there a cumulative heat gain. Usually, there is some wi so that a shallow (1–3 metres) mixed layer is forme

ow this, there is a small negative thermocline arating the warmed surface waters from the un- rmed deeper waters. The heat will be lost, and l associated thermocline will vanish, if the nighttime ling exceeds the daytime heating. If the heat is not it is mixed downward and the associated thermo- e is found at a depth proportional to the strength the winds. In these cases the thermoclines are nsient. Normally they cannot persist for more than w days and eventually join the seasonal thermo- e. This seasonal thermocline can only be destroyed violent turbulence or by a long continued process h as winter cooling.

The positions of the seasonal and transient ther- clines for the period March through November, 6, at Ocean Station " P " are illustrated in Figures , b, c. Temperature-depth profiles for specific ods are also shown. These figures show most of types of structures that can occur. Transient rmoclines first occurred in April, and a seasonal rmocline was formed at the end of the month (Fig.). Thereafter, the transient thermoclines occurred h increasing frequency throughout the heating od. Each transient provided a small increase in temperature in the surface layer, and added to magnitude (ΔT) of the seasonal thermocline. ough May, the seasonal thermocline deepened in presence of increasing winds. At the beginning uly (Fig. 38b), a period of light winds, a second rmocline was formed, overlying the old one. ually the winds are sufficient to mix the thermocline n so that a single seasonal thermocline is formed, occurred in 1955, 1957, 1958 and 1959. However, 1956 all heat additions (transients) contributed to upper thermocline while the lower thermocline ained unchanged. During a period of very light ds, August 9 to 17, a third, shallower thermocline ned (Fig. 38b). However, as soon as the wind reased this was driven down to the next level and ed the underlying thermocline. By about mid- tember, transients no longer occurred (Fig. 38c). October, the upper thermocline had been mixed nward and joined the lower thermocline. There- r the thermocline was eroded and deepened.

The depths of the upper and lower limits of the rmocline oscillated between three and five metres n their mean depth and at times as much as 20 res from their mean depth. This is attributed to rnal waves having a spectrum of periods from eral minutes to at least half a day (Tully and vando, 1962). Further, the oscillations of the top bottom of the thermocline are not always syn- onous, hence the thickness of the thermocline may vary considerably.

Because of this ambient variation it is not possible to determine the gradient, $\Delta T/\Delta Z$. However, these variations do not affect the determination of the temperature difference in the thermocline which accompanied by the mean depth and standard deviation of its depth limits provides the only accurate description of the temperature structure.

Unless affected by processes of convergence or divergence, three general rules of behaviour may be deduced. First, the thermocline does not ascend toward the surface. This would require the unmixing of the warmed and unwarmed waters which cannot be accomplished by any mechanical means. However, the mixed layer can deepen in the presence of any process which will increase the mixing, or remove the heat. Second, heat is not transferred downward through the thermocline. Such transfer requires mixing, which must lower or destroy the thermocline. Hence, each thermocline forms a cover protecting the waters below it against further heating from the surface. The upper limit of a thermocline defines the depth of existing local surface influence. Third, in and below the thermocline the temperature and structure can only be changed by internal processes, such as mixing or advection. In most oceanic areas such processes are slow, hence aside from internal waves the sub-thermocline temperature structure is constant, or changes slowly during periods of weeks or months.

These discussions are summarized from Figure 39 which shows, in generalized form, the sequence of structures throughout the year in the upper 200 metres of depth. The oceanographic structures in the surface layer respond to the local surface processes (heating, cooling, wind mixing). The seasonal thermocline represents the cumulative effects of these processes and marks the limit of their influence. The depth of a seasonal thermocline remains fairly constant from the end of June until the beginning of the cooling season in mid-September. At this time cooling and evaporation become dominant. The density of the surface waters increases and convective mixing occurs. The process erodes the thermocline gradually through the cooling season, below the limit of any wind mixing. In the Subarctic Region the process stops at the depth of the permanent halocline because its stability precludes further downward mixing. The effects of surface cooling usually reach this depth in January or February. Thereafter the whole upper zone may continue to cool.

The waters immediately above the halocline are

exposed to surface influence (cooling) only during the short interval in late winter when the seasonal thermocline has vanished. The properties of these waters are established at this time and are preserved within reasonable limits through the remainder of the year, under the seasonal thermocline. Figure 40 shows the temperature at the surface and 100 metres depth observed twice daily at Ocean Station " P ". These data, which reflect ambient variations due to internal waves, show, in most years, periods of cooling or warming at 100 metres depth during which temperature changes do not exceed 1°C. In most of the Subarctic these waters are easily recognized in the salinity structure, and occur at the top of the halocline (bottom of upper zone) (Dodimead, 1961a).

Other features of the temperature cycle of the waters at Ocean Station " P " and in the eastern Subarctic have been reported by Hollister (1956), Robinson (1957) and Tabata (1961). Sea surface temperatures reach a maximum (13–14°C.) in late August and a minimum (5–6°C.) in late March at Ocean Station " P " (Fig. 41). The annual range is between 7°C. and 8°C. This is the range noted in the sea surface temperature charts (Fig. 12a, c) and may be assumed to be related to the uniformity of incident energy in the Subarctic (Fig. 10, Tully and Dodimead, 1957). Too, the annual cycles of air and sea surface temperatures are similar at Ocean Station " P " (Fig. 42). In winter, the rate of change of air temperature is not as uniform as that of the sea surface temperature. The most marked temperature variations in the water column occur from surface to a depth of 30 metres (Fig. 43). At 50 metres depth, the annual variations are one half the magnitude of those at the surface.

Typical summer temperature structures in the Subarctic are shown in Figure 34. In the western Subarctic, particularly in the Okhotsk and Bering Seas, the temperature structures exhibit a marked positive gradient within the halocline. This results in a subsurface minimum, commonly referred to as dichothermal water (Uda, 1935) which is always associated with the bottom of the upper zone; and a subsurface maximum, commonly referred to as mesothermal water, which occurs in the halocline. The coldest dichothermal water occurs in the regions of winter ice cover.

Uda (1962) has classified the dichothermal structure according to the mode of formation and subsequent behaviour. One type is the consequence of the seasonal cycle of heating and cooling. It occurs in areas where, during the winter, the waters in the upper zone become colder than the waters in the halocline (western Subarctic, particularly Okhotsk and Bering Seas and the northern Gulf of Alaska). positive thermocline is formed in the halocline belo the isothermal upper zone. With the advent of t summer heating, a negative thermocline is form and continues to grow through the heating perio In this type of dichothermal structure there is an is thermal " temperature-minimum " layer situat between an upper negative and a lower positive the mocline. The characteristic temperature (T_m apparently changes very little during the course of t summer period. This is consistent with the the mocline model deduced at Ocean Station " P ".

A second type of dichothermal structure origina by the same process in the areas of sea ice formatic primarily in the Okhotsk Sea. The cold, more sali iso-layer remaining after the formation of ice exten to depths between 75 and 150 metres. The te perature of this layer is between –1.8°C. and 1.0° The layer (in the Okhotsk Sea) follows the persiste circulation (p. 18) and moves through the mid Kuril passages into the western Pacific. Because mixing along its path, especially in the island passag the layer becomes warmer (to about 1°C.). A porti of the layer underruns the upper layers of the wa (to 20°C.) saline (to 35‰) Kuroshio to form the gre est part of the Oyashio Undercurrent. The pass at depth of the water through the Kuril passages a its (modified) continuation as the Undercurrent c be " traced " by the horizontal distribution of dic thermal temperature or by means of a salinity mi mum at depth. The outflow through the mid Kuril passes persists throughout the entire year. T strength of the Undercurrent varies from year to y and appears to be related to the meteorological con tions in the area (Kajiura, 1949).

In the lower zone the temperature generally creases with depth to about 3°C. at 1000 metres de and about 1.5°C. at 4000 metres depth. Howe in the Okhotsk Sea, the temperatures below the s surface minimum (dichothermal temperature) usu y increase with depth to about 3°C. at the limit of e observations.

The temperature profiles along a north-south tion (Fig. 35) show that the greatest regional char occur in the lower zone. Near the Subarctic bou ary, a marked negative gradient occurs from the li of the upper zone to about 600 metres depth. H ever, at about lat. 49°N., a slight tempera maximum is present at depths of about 400 met This feature has been observed as far east as k 155°W. but a little further to the south (approxima lat. 47°N.). This maximum is not a direct re of the seasonal heating and cooling process sinc

ars well within the lower zone. Presumably it is s ciated with advection.

Dissolved Oxygen

he principal features of the dissolved oxygen structure can be described from data observed at an Station " P " (Fig. 44). The summer structure exhibits a fairly marked maximum at about 30 to 5 metres depth. From about 100 to 300 metres depth, an oxycline is present. The values then decrease gradually to a minimum at about 800 metres depth, and then increase below this. In winter, a relatively homogeneous upper layer corresponding to the isopycnal upper zone exists. Other than the changes in the upper zone, the structure is relatively constant throughout the year.

In Figure 45 are shown the dissolved oxygen concentrations at selected depths. In the upper zone (0–100 m.), marked annual variations occur, especially in the upper 30 metres of depth. The near surface waters (0–30 m.) are saturated or supersaturated with dissolved oxygen throughout the year. However, the solubility and hence concentration also varies with temperature; this results in maximum values in late winter, and minimum values in late summer without considering biological factors.

There is little evidence of annual variations below a depth of 100 metres, the limit of the upper zone. However, in both the halocline and the lower zone, appreciable variations with a period greater than one year are evident.

Typical oxygen profiles corresponding to the salinity and temperature profiles already discussed are shown in Figure 34. These profiles show the existence of a fairly sharp oxycline between 100 and 300 metres depth throughout the northern Subarctic. But, as shown in Figure 35, near the Subarctic boundary the oxycline becomes indistinct and extends from near the surface to about 600 metres depth.

Vertical Sections of Salinity, Temperature and Dissolved Oxygen

Several vertical sections of salinity, temperature and dissolved oxygen and their locations for each year, 1955 through 1959, are shown in Figures 46 to 99. Where possible, the locations of the sections are the same for each year. Oxygen data were not always available. The figures, which show the distribution of properties from the surface to 1000 metres depth, identify the features of structure in the Subarctic and permit comparison of conditions during these years.

1. *Salinity.* In the figures showing salinity structure, an upper zone, halocline and lower zone have been defined, where adequate data were available from logarithmic plots. In those figures where the upper zone has been identified, the absence of a halocline zone indicates that no sharp discontinuity existed between the halocline and the lower zone.

In general the upper zone extended to depths generally less than 150 metres. A slight vertical salinity gradient, or a secondary halocline, associated with the thermocline existed in this zone during the summer. The bottom of the halocline usually corresponded in position to the depth of the isohaline of 33.8‰.

Near the Subarctic boundary the salinity at the bottom of the halocline increased to about 34.0‰ and a salinity minimum (approximately 33.9‰) occurred in the lower zone, close under the halocline. This salinity minimum deepened to the southward.

Off the coast of Japan, the sections (Fig. 47, 68, 80 and 91) show a marked salinity boundary at lat. 40°N. which extended from the surface to a depth of about 400 metres and clearly indicates the marked discontinuity of oceanographic structure and properties at the confluence of the saline Kuroshio and less saline Oyashio systems. Eastward of the area, this feature can be identified but was not so pronounced.

In a section parallel to the Kuril Islands (Fig. 48) a marked deepening of the isohalines occurred off the southern end of the Islands, and water of salinity of 33.6‰ was present at a depth of 500 metres. Such water generally occurred above 200 metres depth and within the principal halocline. This feature is presumably a result of an outflow from the Okhotsk Sea where this type of structure is found. A similar section for the following summer, 1956, does not show this feature to be so pronounced (Fig. 55). As suggested by Kajiura (1949), the intensity of this outflow from the Okhotsk Sea appears to be variable.

A striking feature of the north-south sections through the Aleutian Islands and the Gulf of Alaska is the dome-like configuration of the isohalines in the lower zone. It is easily recognized in all sections in this area. Examples of this feature are shown in Figures 83 to 85. This anticline is a permanent feature and appears to be continuous from the middle of the Gulf of Alaska westward along the southern side of the Aleutian Islands to at least long. 175°E. The halocline was continuous throughout the area of the dome in all available data. However, the upper

zone and halocline were compressed into a shallower depth interval and salinities were usually greater than those in adjacent areas. Too, the lower zone water of salinity greater than 34.0‰ was continuous into the Subtropic Region. Such features suggest a source of saline water into the Subarctic. Immediately northward of the dome, the isohalines dipped downward markedly, indicating a relatively strong westward current (Alaskan Stream) which carries relatively warm, dilute surface water along the southern side of the Aleutian Islands. In the shallow Aleutian passages, turbulent mixing destroys the zone structure.

In the Bering Sea, the upper zone and halocline extended to greater depths than south of the Aleutian Islands. Also, in some areas of the Bering Sea, the principal halocline and lower zone are not easily distinguished and the salinity gradient extended from the bottom of the upper zone to approximately 600 metres depth. These conditions are shown in Figure 95. Over the continental shelf relatively dilute water extended from the surface to the bottom, and a marked horizontal gradient occurred at the edge of the shelf (see Fig. 58). These are common features in all high latitude continental shelf areas. However, unlike conditions off the British Columbia coast, the fresh water was not dissipated seaward off the continental shelf to any extent.

In the eastern Subarctic, the summer latitudinal sections for these years showed that the upper zone and halocline depths did not vary markedly and could always be defined (see Fig. 98). There were no marked horizontal gradients at the surface in the oceanic areas. The winter data (Fig. 89) reflect the same features except that the upper zone was homogeneous.

Off the North American coast at lat. 40°N. relatively dilute water usually extended as far west as long. 140°W. (see Fig. 53). Near the coast, at this latitude, relatively cold saline conditions existed as a result of upwelling, produced by the predominantly along-shore winds during the summer periods (McEwen, 1912).

2. *Temperature.* Vertical sections of temperature are also shown in Figures 46 to 99. All summer sections show that a marked thermocline occurred in the upper zone between 30 and 75 metres depth. Above the thermocline, the water was generally isothermal (and isohaline). Sub-thermocline temperature minima (dichothermal water) which occurred at the bottom of the upper zone (compare with salinity sections) were found over a large part of the Subarctic. Such minima were lowest in the Okhotsk ar northern Bering Seas. Below the minima, there we corresponding temperature maxima (mesotherm water) in the halocline.

In winter, the thermocline was absent and t waters were isothermal (and isohaline) to the top the halocline.

Off the coast of Japan at lat. 40°N. a marked ter perature boundary, corresponding to the salini boundary, was present (Fig. 47, 68, 80 and 91). Ho ever, in the mid-ocean area it becomes less distin necessitating the use of salinity structure to define t Subarctic boundary (p. 3).

Figure 48 indicates the same physical feature as se in the salinity section along the Kuril Islands; name a deepening of the isotherms at the southern e which confirms the outflow of cold water from t Okhotsk Sea.

In the Gulf of Alaska and south of the Aleutian lands, a dome-like structure similar to that in t salinity section occurred in the lower zone (e.g., F 83 to 85). Northward of the dome, the waters we warm (and dilute) and are associated with the we ward flowing Alaskan Stream. In the central p of the Region, south of the Aleutian Islands, the co figuration of the isotherms was markedly differe from that of the isohalines. Southward of lat. 45° and below the summer thermocline there was a fai marked vertical gradient which became greater a extended to deeper depths toward the Subtro Region.

Between lat. 46°N. and 42°N. near long. 145° in summer 1959, there was a distinct temperatu minimum at the bottom of the upper zone and maximum immediately below it in the halocline (F 97). This feature was absent in the temperatu structure to the eastward and in both of the latitudi sections along approximately lat. 48°N. and 38° (Fig. 98 and 99). This dichothermal water was a parently isolated offshore and was not present in t area during the previous years.

In the Bering Sea (Fig. 58), extremely cold wa (−1.0°C.) below the summer thermocline was pres in areas over the continental shelf, but, because of low salinity of these waters, they were not of suffici density to cascade over the continental shelf and cre an intermediate water in the Bering Sea.

3. *Dissolved oxygen.* The oxygen sections are cluded with the salinity and temperature sections each year (Fig. 46 to 99).

In the upper zone, as defined in the salinity structure, a marked oxygen maximum generally occurred between 30 and 50 metres depth in summer and was approximately coincident with the summer thermocline. Concentrations within the maximum were usually greater than 0.6 mg. at./l.

In the Gulf of Alaska and south of the Aleutian Islands, the isopleths of oxygen showed an anticline similar to that noted in the salinity and temperature sections (e.g., Fig. 83 to 85). Also in this area, the oxycline was closely associated with the halocline but seaward of the dome, the oxycline deepened and was no longer coincident. Rather, the gradient and configuration of the isopleths of oxygen were similar to those of the isotherms. Relatively high concentrations were found at considerable depth near the Subarctic boundary and because of high surface temperatures at this latitude relatively low surface values were found.

The oxygen minimum which usually occurred between 800 and 1000 metres depth near the Subarctic boundary rose in the area of the dome to between 400 and 600 metres depth (e.g., Fig. 73).

In the Bering Sea, the isopleths of oxygen had nearly the same configuration as the isohalines. Also, values in the upper zone were greater (0.6–0.8 mg. at./l.) than elsewhere in the Subarctic.

In the eastern Subarctic during winter, oxygen concentrations were relatively uniform in the upper zone (Fig. 64). Maxima were observed in winter, 1957, and were usually found at slightly greater depths than during the summer periods (Dodimead, 1958). Also, slightly greater concentrations were found in the surface waters in winter compared to summer. This is presumably due to increased solubility in the cold water and marked aeration due to storms (compare Fig. 64 and 73).

V. CIRCULATION

Oceanic circulation can be deduced by various methods such as direct-current measurements; distribution of properties on selected surfaces (i.e., at standard depths or on a constant property surface); geostrophic currents or transports compared to an arbitrary reference level; release and recovery points of drift bottles, floats or cards; or theoretical considerations of the effect of wind stress on the sea surface. All these methods except accurate and complete direct-current observations have some short-comings. But, until enough ships and time are available to carry out direct-current measurements, indirect methods must be used. These methods when mutually supporting, permit a reasonably accurate and reliable interpretation of the circulation.

A. Geostrophic Currents

In the absence of direct-current measurements, the most common method of deducing the circulation is from geostrophic currents (calculated from values of temperature and salinity at known depths). They are usually presented as contoured fields of anomalies of dynamic heights (geopotential topography). In such charts, the flow is presumed to be along the contours and the speed is proportional to the gradient across them.

There are a number of limitations to this method, one of which is the choice of a suitable reference level, since the method gives calculated currents which are relative to those existing at the reference level. Thus, if there is appreciable movement at the reference level, the calculated velocities will be different from those found by direct-current observations. A reference level at 1000 metres depth was chosen principally because there are not enough stations with data at greater depths.

Reid (1961) has shown the geostrophic flow at the sea surface with respect to the 1000 decibar surface to agree in general with the average of currents estimated from the set and drift of vessels, and those presented in various atlases for the Pacific Ocean. Further, Barnes and Thompson (1938) have suggested that in the Bering Sea there is little movement at the 1000 decibar level. Dodimead (1961 b) has also suggested that this is an adequate level, particularly to show the direction of flow in the eastern Subarctic. This conclusion was deduced from a comparison of the geopotential topographies of the sea surface relative to 1000 and to 2000 decibars (Fig. 100). The configuration of the isopleths, and hence the direction of surface flow, was almost identical. In some areas, some reservation must be placed on the velocities calculated from the 1000 decibar reference surface since it is apparent in Figure 100, which also shows the topography at 1000 decibars using 2000 decibars as a reference level, that there is some movement at the 1000 decibar level. South of lat. 50°N. the topography at depth was relatively flat, implying little relative movement, and hence in this area the surface velocities calculated from the 1000 decibar level must be fairly accurate. The greatest movement occurred in the northern part of the Gulf of Alaska particularly around the northern boundary of the Alaskan Gyre. Bennett (1959) has shown that during summer, 1955, in this area surface velocities relative to 2000 decibars were about 1.5 times those relative to 1000 decibars. Also, comparison

between drogue measurements made aboard the U.S.C.G.S. *Explorer* in 1959 and dynamic topographies computed from hydrographic data near the Aleutian Islands shows that the latter method does not result in true velocities in this area. This discrepancy, no doubt, applies to most areas contiguous to land or oceanic fronts.

Also, it is difficult to believe that a uniform reference level exists in a north-south direction in the Subarctic. Neumann (1955) has shown that the reference level rises from the Equator towards the Poles in the Atlantic Ocean. These problems should be investigated further but in spite of these limitations considerable information can be gained from geostrophic calculations. The circulation at the sea surface relative to 200 and 1000 decibars, and at 200 and 500 decibars relative to 1000 decibars are discussed. The choice of these particular levels is based on the features of the salinity structure. The 200 decibars surface coincides approximately with the bottom of the halocline (see Salinity, p. 11). This surface separates surface waters that are directly influenced by seasonal processes of heating, cooling, precipitation, evaporation and wind action, from the deeper waters whose properties are relatively constant. The circulation at 500 decibars represents the features of the circulation in the deeper waters.

1. *Surface relative to 1000 decibars.* The surface circulations relative to 1000 decibars are shown in Figures 101 to 108 and are schematically summarized in Figure 109. In the extreme western Pacific, the warm, saline Kuroshio Current moves northward along the Japanese islands and the main flow turns eastward at about lat. 36°N. (well south of the Subarctic boundary). This water continues eastward as the North Pacific Current to about long. 150°W. where it moves southward.

Part of the Kuroshio continues northeastward to about lat. 40°N. where it meets the cold southward-moving less saline current (Oyashio) which is present along the eastern side of the Kuril and northern Japanese islands. At the confluence of the two currents, extensive mixing occurs both horizontally and vertically. Water properties in this locality are extremely variable and complex and the area is characterized by eddies. This mixed water continues eastward as the " West Wind Drift ". Geostrophic calculations show that it has a much slower speed than the Kuroshio and advances at about 2–4 nautical miles per day (4–8 cm./sec.). Uda (1962) suggested this speed is relatively uniform to about 300 metres depth. The water continues to the eastward with a slight northward component which carries it to about lat. 45°N. in the vicinity of long. 180° where it continues eas ward in a near zonal path to approximately 300 mil from the Washington-Oregon coasts. Here the wat divides; part turns southward to form the Californi Current; a small part intrudes into the area off th coast of Vancouver Island, and then moves southwar along the coast; and the remainder flows northwar into the Gulf of Alaska. In the area of division, th currents are weak and variable.

The part of the Oyashio that does not actively mi with the Kuroshio and which has properties simil to those of the Bering and Okhotsk Seas moves nort eastward, approaching within 60 miles of the Aleutia Islands in the vicinity of long. 180°. Most of th water moves eastward in a near zonal path at a ra of about two miles per day (4 cm./sec.) (Subarct Current). It eventually flows into the Gulf of Alask and around the Alaskan Gyre, making its return, aft some modification, in the strong (8–10 miles/da 16–20 cm./sec.) westward flowing current (Alaska Stream) along the southern side of the Aleutian Island

The remainder of the water forms a gyre with i centre at about lat. 50°N., long. 165°E. The wat at the edge of the gyre mixes with the water of t Alaskan Stream, moves westward to the end of t Aleutian chain and into the Bering Sea west of At Island, where it moves eastward along the northe side of the Aleutian Islands mixing with the ne surface water that has flowed northward through t Aleutian passages. Some of this mixed water flo northward over the continental shelf through Beri Strait into the Arctic Ocean. The main circulati is cyclonic (counterclockwise) and water in the nort western Bering Sea flows southward along the Siberi coast. One part becomes the East Kamchatka Cu rent, the other is absorbed in the cyclonic gy present in the central Bering Sea. Some of the wat of the East Kamchatka Current moves into t Okhotsk Sea through the northern Kuril Islan Here the structure of the water is modified as it c culates in a slow cyclonic gyre, eventually moving o through the central passages of the Kuril Islands.

The surface circulation in the Subarctic is, for t most part, closed. It is a major gyre with seve subsidiary gyres superimposed on it. As a result studies concerning fresh water accumulation, Tu and Barber (1960) have suggested that six years a necessary for the round trip. Drift bottle experime indicate that it may be as short as four years. though some water is lost through Bering Strait, t main surface flow out of the Subarctic occurs at t Subarctic-Subtropic boundary through the Califor Current system.

The significant features of the Subarctic circulation a::

(1) A major gyre with four subsidiary gyres; Bering Sea, Western Subarctic, Okhotsk Sea and Alaskan. The Alaskan Gyre extends along the southern side of the Aleutian Islands.

(2) The confluence of the Oyashio and Kuroshio.

(3) The division of the waters off the North American coast.

(4) The strong westward flowing current (Alaskan Stream) immediately south of the Aleutian Islands.

It will become evident that most of these surface atures of circulation persist at the deeper levels. In me cases they are clearly evident, but in others they e less distinct than at the surface.

2. *200 decibars relative to 1000 decibars.* This cir-lation is shown in Figures 110 to 117 and the per-tent features are illustrated schematically in Figure 8. In general, the major features are similar to those the surface relative to 1000 decibars. All four gyres e present. However, the eastern edge of the West-n Subarctic Gyre appears to extend further east-ard than at the surface. The zonal flow centered ong lat. 45°N. divides nearer the North American ast than the surface flow in this area. Also, the ater south of lat. 45°N. does not appear to intrude into e area off the coast of Vancouver Island.

In summer, a northward flow off the Washington-regon coasts occurred in all years except 1958. This the California Undercurrent. In the western Sub-ctic there is a southward flow called the Oyashio ndercurrent. Throughout the Region, the speed the flow at this level is about one half that at the rface.

3. *500 decibars relative to 1000 decibars.* The cir-lations at 500 decibars are shown in Figures 119 to 26. A schematic of this flow (Fig. 127) shows that is similar to that at 200 decibars. However, the elocities are less, indicating a reduced flow in the eeper waters. The division of the flow off the North merican coast appears to be further south than at allower levels. Too, the main westward flow long the Aleutian Islands and associated with the laskan Stream does not appear to intrude as far into he central Bering Sea. Instead, the movement is enerally westward almost to Kamchatka where it oves southward and circulates around the Western ubarctic Gyre or continues eastward.

4. *Surface relative to 200 decibars.* Earlier works sually considered that the surface circulation deduced rom this level was the same as that deduced from a deep reference surface (e.g., 1000 metres) and this is true in some areas. However, as seen in Figures 128 to 135 and summarized in Figure 136, there are some obvious differences, particularly in the mid-ocean area and in the vicinity of the Aleutian Islands.

In the mid-ocean area, flow computed between the surface and 200 decibars has a component to the north; whereas, the flow at the surface and other levels referred to 1000 decibars moves in a near zonal path. In the western Subarctic, from the vicinity of the Kuril Islands, the surface water appeared to flow toward the Aleutian Islands as far eastward as long. 175°W. instead of 175°E. as shown in Figures 109 and 118. From 175°W. water appeared to flow into the Bering Sea through the Aleutian passages or westward along the southern side of the Islands and then into the Bering Sea.

The apparent flow at the surface relative to 200 decibars can only be regarded as a surface tendency and does not always indicate a flow or continuity. That is, the surface flow is dependent upon the flow in the deeper water and is included in the total flow shown in the 0 to 1000 decibar charts.

5. *Variations 1955 through 1959.* Any major changes in the circulation pattern would materially affect the distribution and structure of the waters. Some variations in the circulation have been noted and these generally occurred at all depths.

Dodimead (1961 b) has discussed the year-to-year variations in the geostrophic circulation in the eastern Subarctic. He showed that the most marked anomaly in the surface circulation occurred in 1958. There was a high in the dynamic topography about 200 miles off the British Columbia coast and, associated with this, a southward flow near the coast. In other years (1955, 1956, 1957 and 1959) there was a northward flow in the approaches to the coast. He suggested that changes that occurred in the surface flow were dependent upon the flow in the deeper waters.

At 200 decibars relative to 1000 decibars the area of division (at about lat. 45°N., long. 135°W.) was furthest south during 1958 (Fig. 115). Also, in 1957 and 1959, this circulation was slightly different to that observed in 1955 and 1956 but not to the extent observed in 1958. Dodimead (1961 b) concluded that these changes, in part, accounted for the observed changes in water properties off the British Columbia coast.

The surface flow into the Gulf of Alaska was more northward in 1958 than in other years. This feature was most apparent in the surface circulation relative

to 200 decibars (Fig. 133). Also, the centre associated with the Alaskan Gyre shifted westward. Presumably, more water flowed into the Gulf of Alaska during 1958, and hence into the Alaskan Stream. As a result, there was marked westward extension of the Alaskan Stream, which was apparently accompanied by a reduction in the extent of the Western Subarctic Gyre. Kitano (1958) has shown minor changes in the extent of the Alaskan Stream in other years.

Callaway (1960) has shown the oceanographic conditions and flow that occurred in the vicinity of the Aleutian Islands during summer 1957. Some seasonal and yearly variations that occurred in the temperature structure in this area are shown in Figure 137 (INPFC, 1959). Figure 137a shows the vertical temperature structures along three longitudes during July, 1957. The warm water associated with the Alaskan Stream (4°C.) was confined to the southward of the Islands at long. 165°W. and extended well below the depth of Unimak Pass (approx. 60 metres). At long. 175°W., the warm water extended north and south of the Islands indicating an intrusion of water into the Bering Sea near this longitude. Further westward at long. 175°E. this water was displaced southward of the Islands by the colder Bering Sea water. However, a year later (July, 1958) conditions at long. 175°E. were changed (Fig. 137 b). The Bering Sea water had retreated northward and warm water was found north and south of the Aleutian ridge. These structures show the variability of flow in the Alaskan Stream which is not immediately evident from the horizontal charts of geostrophic currents.

B. Drift Bottles

Drift bottles and floats have provided another method of ascertaining the general surface circulation. Sealed bottles, containing a questionnaire and promise of a reward, or floats with an identifying number, were released in significant numbers at known positions.

Some recent Japanese experiments have been successful in areas where the floats have been captured in gillnets by the high seas fishing fleets. The results of two programs (Taguchi, 1959; Hakodate Marine Observatory, 1961) in the western Subarctic and Bering Sea are summarized in Figure 138.

A limited drift bottle program has been carried out by the Biological Laboratory, Seattle, in the Aleutian area where the possibility of recovery is remote. However, some interesting recoveries have been made which indicate the flow from the central to eastern Subarctic (Fig. 139).

Numerous drift bottle releases (1000 bottles each have been made by the Pacific Oceanographic Group in the eastern Subarctic, usually from Ocean Station "P". The returns were between 4% and 7%. Dodimead and Hollister (1958) analyzed these data and showed that there were gross fluctuations in the surface currents during the period 1956 through 1958 and these results agreed with the geostrophic circulation. Some of the results are shown in Figure 140 and a complete summary of the program is reported by Dodimead and Hollister (1962).

Because of the nature of such experiments only general conclusions can be drawn, but several features of the circulation are apparent. In most cases they are in agreement with those deduced from geopotential topographies. In some cases they show features of the surface circulation not readily apparent in the calculated currents. They show surface flow:

(1) northward between Attu and Komandorski Islands;

(2) from as far south as lat. 46°N. between long. 140°W. and 145°W. into the Gulf of Alaska;

(3) around the Gulf of Alaska (Alaskan Gyre);

(4) along the southern side of the Aleutian Islands into the Bering Sea and eastward along the northern side of the Islands;

(5) circulating within the Subarctic Region;

(6) from the Subarctic Region into the California Current system, toward the Hawaiian Islands, and then westward to the Philippine and Japanese islands;

(7) around the Western Subarctic Gyre.

C. Wind-Induced Mass Transport

Some of the more advanced theoretical works on oceanic circulation (Freeman, 1954; Hidaka, 1955; Charney, 1955 a, b; Veronis and Morgan, 1955; Morgan, 1956; Veronis and Stommel, 1956; Veronis, 1956; and Arons and Stommel, 1956) have been reviewed by Bowden (1958). He states: "It is now generally accepted that the chief features of the mean circulation in the upper layers are due, directly or indirectly, to the wind stress. It is less certain to what extent the influence of the wind affects the deeper layers or how the circulation as a whole responds to change in the winds." Recently, Fofonoff (1962 a) has investigated these problems. This work has been based on the study of steady-state transport of mass in the oceans as a function of the curl of the wind stress by Sverdrup (1947), Stommel (1948) and Munk (1950). From these Fofonoff has developed a model for the computation of the steady-state transport

ting with the grid presentation of mean monthly ometric pressure he computes, in sequence, the dient winds, the stress on the sea surface, the Ekman face) transport, the geostrophic transport and the l transport. The results of these computations e been published for each month since January 5 (Fofonoff, 1960 a, b, c, d, e; 1961). These rts show the steady state that would result if the ometric pressure situation persisted, or if the ocean onded with a lag less than one month. Present ications are that the Ekman currents respond in a days, hence much shorter (5-day) means should used. However, the response at depth may be yed or integrated in some manner over periods as g as eight months. The charts show the ultimate ct, and taken in sequence, month to month, indi- the trend of development of the flow.

he annual mean geostrophic transports for the years 5–59 are shown in Figure 141. Fofonoff (1962 b) pared the mean geostrophic transport for the -year period 1955–59 with the transport determined n the NORPAC data, 1955. Favorite and Morse (62) compared the wind (mean geostrophic trans- t) and calculated geostrophic (volume) transport fo July and August 1958 (Fig. 142). In general, th e works showed good agreement between the two thods and therefore transports calculated in this nner can be considered an aid in the assessment of sent, and possibly future, conditions.

VI. HORIZONTAL DISTRIBUTION OF SALINITY AND TEMPERATURE

Unique features of the salinity and to some extent th temperature structures provide a method of show- in the continuity and distribution of water properties in the Subarctic. The horizontal distribution of sa nity and temperature on the following surfaces are sh wn and discussed for the years 1955 through 1959: a 10 metres, at the bottom of the upper zone, on the su face of salinity = 33.8‰ (a convenient index for the b tom of the halocline), and on the surface of salinity = 4.0‰ (representation of the deeper waters).

The selection of surfaces of constant salinity for the h izontal presentation of properties is a departure m the usual procedure of using surfaces at standard d ths or surfaces of constant density, but are pref- e ble because of the unique salinity structure. Com- p ison of plots of temperature on constant density l on constant salinity surfaces show that they are similar because density is salinity dominated. There- fo e, they are equally applicable for presentation of the c ditions and features in the Subarctic. Because horizontal distributions show in greater detail the conditions discussed under vertical sections (p. 15) some duplication of discussion may occur.

A. Surface

Properties at the 10 metre level (Fig. 143 to 158) represent conditions in the mixed layer (surface to top of thermocline) in summer or in the upper zone in winter. They are considered to be more representative of the prevailing conditions than those at the sea surface, which are subject to diurnal variations.

1. *Salinity at 10 metres depth.* In general, the isohalines in the mid-ocean between lat. 35°N. and 45°N. tended to have a zonal configuration (Fig. 143 to 150). Along the coasts there were fairly marked gradients and irregularities in the distributions. These conditions are attributable to the current systems, land drainage and local winds. The least saline water occurred over the continental shelf from Bristol Bay to the Gulf of Anadyr and in the northern part of the Okhotsk Sea. These low values are primarily due to ice melt and local runoff.

Dilute water was also generally present off the Columbia River. Further south, off the coast of California, salinities were generally high, and are presumably a result of the lack of land drainage and the occurrence of upwelling associated with the northwesterly winds prevalent during summer periods. The same feature was observed off the coast of Vancouver Island in summer, 1959 (Fig. 150). Tully (1942) observed similar conditions in the approaches to Juan de Fuca Strait. Between the northern tip of Vancouver Island and the Queen Charlotte Islands (lat. 51°N. to 55°N.) low salinity water (less than 32.4‰) generally extended a considerable distance offshore, often in the form of tongues. Presumably, these are associated with the meandering characteristics of the weak and variable flow in this area (Doe, 1955).

A salinity maximum (32.8‰ to 33.1‰) was usually present in the Gulf of Alaska southward of Kodiak and the Shumagin Islands. This feature is considered to be associated with the dynamic centre of the Alaskan Gyre. Southward of the Gyre, the salinity of the waters generally decreased to a minimum (32.6–32.7‰) then increased again to southward. The minimum (centered about lat. 48°N.) was more pronounced in some years than in others.

Near the Subarctic boundary, a fairly marked meridional gradient was present marking the transition between Subarctic and Subtropic Waters. Other

areas of high salinity water (greater than 33.0‰ during the summer months) occurred in the central Okhotsk and Bering Seas. These two areas of high salinity are considered to be permanent features associated with the cyclonic circulation. Presumably the salinities are greater during winter when "freezing-out" of fresh water occurs, particularly in the Okhotsk Sea.

Off the northern Japanese islands, the salinity distribution exhibited marked gradients and irregularities which occurred in the confluence of the relatively low salinity, cold Oyashio and high salinity, warm Kuroshio. These have been smoothed considerably in the interpretation for the figures.

The most extensive oceanographic coverage during the winter months was made in the eastern Subarctic. The features of the salinity distributions were essentially the same as observed during the summer months in this area. However, during winter, the salinities appeared to be slightly greater (0.2‰) and the isohaline was closer to the coast (compare Fig. 145 and Fig. 146).

2. *Temperature at 10 metres depth.* It was difficult to obtain a complete synoptic picture of temperature at 10 metres depth in the western Subarctic and Bering Sea because there is always a progressive change of temperature during the extended period (May–September) over which the observations were made. However, the data in the eastern Subarctic were taken when the seasonal temperature changes are not significant (Fig. 41) and may be considered approximately synoptic (Fig. 151 to 158).

The configuration of the isotherms coincides with the surface circulation (Fig. 109). The isotherms lay east-west, except near the continental margins. A meridional gradient of temperature is apparent in mid-ocean.

In the Gulf of Alaska, there was usually an area of temperature minimum. In summer, this cold centre did not usually coincide with the salinity maximum associated with the dynamic centre of the Alaskan Gyre; however, in winter they were coincident. High salinity, cold water, being entrained into the upper zone, could account for the apparent relationship in these distributions and the centre of the Gyre. However, in summer, other processes must also affect the surface temperature distribution in this area.

Off the northern Japanese islands, there were several filaments of closely spaced isotherms. These indicate the distinct fronts associated with the confluence of the warm Kuroshio and cold Oyashio systems.

The pattern of winter temperature distribution w similar to that observed in summer (compare Fig. 1 and 154) although the water was about 7°C. cold This difference is near the range observed at Oce Station " P " (Fig. 41) and results from the uniform of summer heating from lat. 40°N. to 60°N. (Fig. 10

B. Bottom of Upper Zone

The bottom of the upper zone (top of the haloclir is the limit of winter convection or turnover. Wit small limits of error, the salinity and temperature d tributions at this level identify the isohaline and i thermal upper zone during the previous winter (Do mead, 1961 a); thus, during summer, the tempe tures at this depth are equivalent to those occurri at the period of minimum temperature during t previous winter (p. 14).

Properties at this level and at 10 metres dep adequately describe the features of the upper zone.

1. *Depth.* The depth of the upper zone var between 50 and 275 metres, but, in general, it occurr at approximately 100 metres (Fig. 159 to 166). was shallowest near the American coast, and t shoaling is believed to be associated with coastal u welling which occurs in this area during sumn (p. 21). In the vicinity of the Alaskan Gyre, its dep was generally less than 75 metres. This shoaling w associated with the dome (anticline of lower zo water) shown in the vertical sections.

The zone was deeper in the vicinity of the Aleuti Islands where a maximum of 275 metres was fou during summer 1958 (Fig. 164). The deepening m be attributed to the considerable internal mixing d to tidal turbulence in the island passages and t zones are difficult to define.

2. *Salinity.* The salinity at the bottom of t upper zone (Fig. 167 to 174) is generally similar that at 10 metres depth. The most saline wa (33.2–33.4‰) occurred in the vicinity of the Aleuti Islands, Bering Sea and near the Subarctic bounda Relatively saline water (33.0–33.2‰) was present the Alaskan Gyre and usually extended westwa along the southern side of the Aleutian Islands, c responding in position to the doming of the isohali and isotherms (p. 15).

In the eastern Subarctic there appeared to be slight seasonal variation from winter to the follow summer (compare Fig. 173 and 174) in the salin at the bottom of the upper zone; the values w about 0.2‰ higher during summer. This behavio is the converse of that at 10 metres depth and h been explained on page 11.

Temperature. The temperature distributions at the bottom of the upper zone are shown in Figures 177 to 182. The coldest waters were found in the Okhotsk and northern Bering Seas which are covered by ice during winter. The warmest waters occurred at the Subarctic boundary. In the eastern Subarctic, the summer distributions were similar to those that occurred in the previous winter, because heat is conserved under the seasonal thermocline (compare Fig. 177 and 178).

A tongue-like distribution of relatively cold water extended eastward from the Kuril Islands. The general increase of temperature to eastward suggests that these waters are warmed en route in the Subarctic Current by mixing with the warmer water above and below.

C. Surface of Salinity = 33.8‰

The bottom of the halocline coincides closely with the isohaline surface 33.8‰. Hence, it is convenient to interpret the depth and temperature on this surface as functions of salinity rather than make the logarithmic analysis. The features on this surface adequately define the character of the water at the boundary of the halocline and lower zone.

1. *Depth.* The depths of this surface are shown in Figures 183 to 190. This surface, like the top of the halocline, also shoals in areas of upwelling and deepens in areas of mixing (tidal currents, etc.). The surface generally occurred at depths between 175 and 225 metres, but in some areas, it was found at depths as shallow as 150 metres (Alaskan Gyre) and as deep as 50 metres (Okhotsk Sea). In the Bering Sea, the depth was generally greater than 250 metres, the shallowest depths being near the continental shelf.

2. *Temperature.* Fleming (1958) pointed out the marked similarity in temperature distribution on the surface of salinity = 33.77‰ and the geostrophic circulation at the 200 decibar level during summer, 1956. From a comparison of Figures 191 to 198 (temperature distribution on the surface of salinity = 33.8‰) and Figures 110 to 117 (geostrophic circulation at 200 decibars) it is obvious that there is a marked similarity except off the Washington-Oregon coasts where the computed flow was northward, opposite to that implied by the isotherms.

A tongue of cold water extended eastward from the Kuril Islands. A similar feature was evident in the temperature distribution at the bottom of the upper zone. The general increase of temperature to the eastward suggests that, since this water has no contact with the surface, the warming must be due to advection of warmer water, presumably from the south, the only source of such water. Southward of this tongue in the western and central Subarctic there was a marked meridional gradient. The isolated cold areas south of the Aleutian Islands and in the Gulf of Alaska mark the peaks of the anticline in the sub-halocline structure. Over most of the Bering Sea, the temperatures of these waters varied between 3.5°C. and 3.75°C.

D. Surface of Salinity = 34.0‰

The surface of salinity = 34.0‰ lies well within the lower zone and, thus, is considered to represent its character to approximately 1000 metres depth. Near the Subarctic boundary where the occurrence of a salinity minimum results in the presence of two surfaces of salinity = 34.0‰, the deeper surface is used. Water at and below this level is continuous with that in the Subtropic Region.

1. *Depth.* Figures 199 to 206 show that shallowest depths (less than 250 metres) occurred in the area of the anticline (associated with the Alaskan Gyre) and its extension along the Aleutian Islands. In some years, the shallow depths in this area do not appear to be continuous suggesting a circulation of the lower zone waters southward into the mid-ocean area where they may be absorbed in the eastward flow. Between the anticline and the Aleutian Islands, the depth of this surface increased markedly to approximately 500 metres. Southward of the anticline, the downward slope of this surface extended southward of the Subarctic boundary. Near the North American coast the surface shoaled to approximately 200 metres depth.

The greatest depths were present in the Okhotsk Sea (greater than 800 metres) and on the eastern side of the Kuril Islands indicating that vertical mixing occurred to greater depths in this area than in other parts of the Subarctic. In the eastern Bering Sea, the surface extended to depths greater than 500 metres.

2. *Temperature.* The distributions of temperature on the surface of salinity = 34.0‰ (Fig. 207 to 214) show that the coldest water (1°C. to 2°C.) occurred in the Okhotsk Sea, suggesting that these waters originated at the surface as a result of extreme cooling and subsequently were mixed downward to these depths. Too, the unique temperature and salinity structures (Fig. 34) indicate that there is a very small exchange of water at these depths between the Pacific Ocean and Okhotsk Sea. Evidently it can be considered an almost isolated body of water. Some outflow from the Okhotsk Sea is noted by the presence of low temperatures, on the eastern side of the Kuril Islands.

A tongue of relatively cold water which occurred as a temperature minimum was confined to the area north of lat. 45°N. and south of the anticline along the southern side of the Aleutian Islands, and was not associated with the doming of the isohalines and isotherms. Instead, this water, like the overlying waters, was associated with the eastward flowing current. As this water moves eastward, it warms, and loses its characteristic temperature (less than 3.75°C.) in the Gulf of Alaska.

In sharp contrast to this cold water, a tongue of warm water apparently intruded northward along the North American coast. Its seaward boundary is marked by an appreciable gradient and appears to result from a convergence of the subsurface eastward and northward flows. Its northern boundary extended to the coast of British Columbia, but was less distinct.

Over most of the Bering Sea, the temperatures on this surface were between 3.5°C. and 3.75°C. and thus were similar to those at the surface of salinity=33.8‰. In this area, the lowest temperatures were found in the eastern and northern Bering Sea.

VII. DOMAINS

The usual method of identifying unique features of an area or region is by temperature-salinity relationships which define water masses. In this manner, Sverdrup *et al.* (1942) have identified Subarctic and Central Pacific Water which are distinct. More recently, numerous attempts have been made to subdivide Subarctic Water by this method (Hirano, 1958; Dodimead, 1958; Kitano, 1959; Favorite and Hebard, 1961). The net result of all these studies is a fan of curves as illustrated in Figure 215, defining a gradation of properties which are arbitrarily subdivided. The definitions in this sense are inconclusive. From the previous discussions, the unique feature of the Subarctic is the salinity-zone structure. Distributions of temperature and salinity have been discussed on significant surfaces deduced from the salinity-zone structure; e.g., 10 metres, bottom of upper zone and salinity surfaces of 33.8‰ and 34.0‰. From these distributions, it is possible to define " domains " in the Subarctic, and this approach has been adopted in the section.

The concept of a domain contains the ideas of consistent properties, structure, behaviour (flow, heating and cooling, etc.), climatic locality and continuity. It does not depend on any one of these, which might occur in widely separated localities, but on a rational consistency in all aspects. Also, it is possible to use any convenient index or combination to define the e tent of the domains and this makes it possible to sur marize the variations that have occurred. Specif domains have been identified in the upper zone whe the properties of the water are predominantly i fluenced by such factors as seasonal heating and coo ing, precipitation, evaporation and wind mixing; an in the lower zone where the properties of the wat are predominantly affected by internal processes suc as advection, diffusion, etc. The halocline represen the transition from the upper to the lower zor domains.

A. Upper Zone Domains

Figure 216 shows five principal domains, based o their temperature and salinity and flow characteristic that are identified in the upper zone—(1) *Weste Subarctic*, (2) *Transitional*, (3) *Alaskan Stream*, (4) *Centr Subarctic*, and (5) *Coastal*.

1. *Western Subarctic Domain.* The general cha acteristics of this domain are:

(a) The temperature structure at all times exhibi a cold subsurface minimum at the bottom of th upper zone.

(b) The depth of the upper zone is between 1(and 150 metres.

(c) Relatively high salinity water prevails; gene ally between 33.0 and 33.2‰ in the surface wate in the Bering and Okhotsk Seas and slightly low values (32.6–33.0‰) in the remainder of the domai Near the bottom of the upper zone, salinities a between 33.0 and 33.4‰.

(d) Within this domain, three cyclonic gyres a present; the Bering Sea, Western Subarctic an Okhotsk Sea. Other features of the circulation a the East Kamchatka and Oyashio Currents.

The extent of this domain can be adequately d fined by temperatures less than 3.5°C. at the botto of the upper zone.

2. *Transitional Domain.* This domain lies ju north of the Subarctic boundary. The gener characteristics are:

(a) The flow is principally zonal, except near th North American coast. There it veers northwa and southward.

(b) Surface waters are warm (warmer than 15° in summer and 7°C. in winter).

(c) Relatively high salinity water occurs throughо most of the domain; greater than 33.2‰ in th surface waters and greater than 33.4‰ near th bottom of the upper zone. However, east of lon

0°W. dilution of these waters occurs.

) A subsurface minimum temperature at the ottom of the upper zone may be present.

) Marked meridional gradients of temperature id salinity occur.

he northern edge of this domain can be identified he 7°C. isotherm at the bottom of the upper zone.

Alaskan Stream Domain. This domain is as- ated with the relatively dilute warm water which s out of the Gulf of Alaska westward along the hern side of the Aleutian Islands and is considered egin at about the longitude of Kodiak Island where flow narrows and accelerates. Coastal water is present in the Alaskan Stream but is modified by considerable mixing due to the strong tidal currents g the Islands and through the passages.

ariations in the extent of this domain can be uced from the distribution of surface water less n 32.6‰ and the relatively warm water in the nity of the Aleutian Islands.

. *Central Subarctic Domain.* This domain lies with- he boundaries of the Western Subarctic, Transi- al, Alaskan Stream and Coastal Domains. The eral characteristics of this domain are:

a) One cyclonic gyre (Alaskan Gyre) is present.

b) The depth of the upper zone extends to ap- roximately 100 metres except in the Alaskan yre where it shoals to approximately 75 metres.

c) The salinity of the upper zone is 32.4 to 32.8‰ n the surface water and 33.2 to 33.4‰ near the ottom of the upper zone.

d) A salinity maximum occurs in the Alaskan yre.

e) The temperature structure may exhibit a sub- urface minimum at the bottom of the upper zone. However, the dichothermal structure may occur nly in parts of the domain.

5. *Coastal Domain.* The oceanographic features of s domain vary markedly from one area to the other, ause of the local variations in runoff, heating and ling, winds, tides and advection; thus, the prop- ies, structure and dynamics of the waters are varia- e. There may be strong tidal currents which cause nsiderable mixing, hence the ocean halocline struc- e is modified and in some areas it vanishes. Up- lling may occur in many localities when the winds e suitable. Because of these and other factors, echanisms are sometimes difficult to define. The own features and mechanisms have been sum- arized in the Appendices which define conditions in specific coastal areas. These now need to be applied to other coastal areas before the features of this domain can be fully summarized.

The extent of this domain can be defined by the isohaline of 32.4‰ in the surface waters (at 10 metres depth). In summer, when this surface lens of dilute water intrudes into the oceanic areas an overlap in the boundaries of this and other domains occurs.

6. *Variations, 1955 through 1959.* Specific domains in the Subarctic associated with the upper zone have been established. Now it is possible to discuss their relationships to one another and relate the sequence of events that have occurred each year.

The extent of the five domains for each year are shown in Figures 217 to 224. One of the most obvious features is the westward and southward extent of the Alaskan Stream. This domain extended further offshore during 1955 and 1958 than in the intervening years, suggesting a fairly pronounced southward component in the circulation of the Alaskan Stream at least in the upper zone.

Although the main body of this water moves westward and then northward through the Aleutian passages, it is evident that a portion of it is dissipated southward into the Central Subarctic Domain. Also this dissipation evidently occurred at different locations along the southern side of the Aleutian Islands, resulting in variations in the salinity of the water south of the Alaskan Gyre in the Central Subarctic Domain. The presence of cells of relatively low salinity water, within this salinity minimum, suggests that this dissipation may be intermittent.

The westward extension of the Alaskan Stream Domain was least during summer 1955. During summer, 1956 and 1958, the westward extension of water less than 32.6‰ was furthest (compare Fig. 143, 144, 146, 148 and 150). In 1958, there was an apparent increase in the amount of water flowing into the Gulf of Alaska and hence into the Alaskan Stream, resulting in a westward extension of warm dilute water associated with the Alaskan Stream and slightly lower salinities in the central Bering Sea than in other years. An increased flow was not apparent in 1956. However, it is possible that the dissipation through the Aleutian passages was small, as evidenced by the slightly higher surface salinities in the Bering Sea; thus, most of the water flowed westward, resulting in a westward extension of the dilute warm water in summer 1956.

Favorite (1961) reported on the variations of surface salinity off the coast of British Columbia, showing that in 1958 the coastal waters (Coastal Domain) extended

further offshore than in 1959. This appears to be related to the circulation pattern, which has been shown to be more northerly in the offshore areas during 1958 than in the other years, and which apparently allowed an offshore movement of the coastal waters. At the same time in the northeastern part of the Central Subarctic Domain, low salinity water occurred.

In contrast to the distribution of low salinity water in the eastern Subarctic, the coastal waters in the eastern Bering Sea did not extend as far off the continental shelf in 1958 as in other years. It has already been suggested that the flow of the Alaskan Stream was greater during 1958 and flow into the Bering Sea was proportionately larger. This would result in an increased flow to the eastward, north of the Aleutian Islands, and a confinement of the Coastal Domain to a narrower band than in the other years.

Off the North American coast, the Coastal Domain did not extend as far seaward in winter as during summer. This may be attributed to intensified vertical mixing and reduced supply of fresh water from land drainage and/or seasonal changes in the offshore circulation. In summer 1959, the Coastal Domain water appeared to be discontinuous along the coast of Vancouver Island; apparently marked upwelling occurred during this period.

The most obvious variation in the extent of the Transitional Domain occurred off the coast of British Columbia. During 1957, this domain moved northward along the coast and reached its furthest extent in 1958. By winter 1959 it had retreated, but not to the position observed in the earlier years.

It appears that a northward shift in the position of the Transitional Domain in the eastern Subarctic was accompanied by an eastward and southward expansion of the Western Subarctic Domain in 1958. The next year, 1959, the eastward extent of the Western Subarctic Domain was furthest, but was not continuous and the easterly extremity occurred as a cell in which the water was not as cold as observed in 1958. This cell was probably a remnant of the water that was present in 1958 near this area.

Variations in the Central Subarctic Domain were most apparent in the Gulf of Alaska. Temperatures at the bottom of the upper zone in the Alaskan Gyre were lowest in 1956 (less than 3.0°C.), being as low as water associated with the Western Subarctic Domain and were evidently generated locally as a result of marked cooling. In 1957 surface temperatures in the northern Gulf of Alaska were high and did not appear to be a result of advection. It appears that marked heating occurred during summer 1957.

The highest surface salinities in both winter and summer in the Central Domain were associated with th centre of the Alaskan Gyre, the area of maximu shoaling of the isohalines. Only in winter did th low surface temperatures appear to be associated wit this centre (see p. 22).

B. Lower Zone Domains

Four principal domains which extend to at lea 1000 metres depth are identified (Fig. 225)—(*Western Subarctic*, (2) *Transitional*, (3) *Central Subarcti* and (4) *California Undercurrent*. Because of the simila ity in flow in the upper and lower zones, these domain in general, underlie those identified in the upp zone, but in the lower zone a new domain, the Cal fornia Undercurrent, is found.

1. *Western Subarctic Domain.* The source of th water is principally the Bering Sea. This water flo southward along the coast of Kamchatka, is modifie by waters from the Okhotsk Sea and then mov principally eastward into the Gulf of Alaska. Hov ever, some of this water extends south of the Subarct boundary in the Oyashio Undercurrent off the coast Japan.

This domain can be adequately defined by a ten perature lower than 3.75°C. on the surface of salini =34.0‰.

2. *Transitional Domain.* This domain lies near t Subarctic boundary. The flow of water is principal eastward, but near the North American coast it vee northward and then southward. In the western an central Subarctic, the domain is narrow and characterized by marked meridional gradients. the eastern Subarctic it broadens and gradients becon less pronounced. The extent of this domain has be identified by a temperature of less than 6.5°C. at t surface of salinity=33.8‰.

3. *Central Subarctic Domain.* This domain repr sents a large portion of the oceanic Subarctic. T waters overlying this domain are characterized by t well defined halocline which is maintained by t recirculation of the relatively dilute surface wate Associated with this domain is the Alaskan Gyre. exists below 200 metres depth and is identified by temperature between 3.75°C. and 6.0°C. on the su face of salinity=34.0‰ and is continuous with wat below the salinity minimum in the Subtropic Regio

4. *California Undercurrent Domain.* This domain associated with northward flowing lower zone wate and is bounded by a marked latitudinal gradient temperature. It can be identified by temperatur

ter than 6.0°C. on the surface of salinity=34.0‰ cannot be identified at the shallower level of ‰. The source of this water appears to be south at. 35°N. in the eastern boundary region of the tropics.

Variations, 1955 through 1959. The extents of e domains for each period, 1955 through 1959, are vn in Figures 226 to 233. Tully *et al.* (1960) e described the changes in these non-seasonal ers along the coast of British Columbia using temature on a constant density surface (σ_t=26.60) rring near the bottom of the halcoline. Tully Barber (1960) compared these isopycnal and halo-e (temperature on the surface of salinity=33.8‰) lyses and showed that they coincided in every ncipal feature. In these studies, it was concluded there was a progressive northward intrusion of Transitional Domain along the British Columbia st in the period 1955 through 1958 (Fig. 225 to). Apparently this domain intruded furthest ing early 1958. Data to 1962 show that it has retreated to the position observed in 1957 and lier. Uda (1962) compared similar occurrences the coast of Japan as reported by Uda (1960) and kenouti (1960). By contrast with the sequence off Canadian coast, the order of the warm water sions was 1955 (strongest), 1956, 1957 and 1958 akest), just the reverse of conditions off the Canadn coast. Thus it appears that when cold conditions st off the coast of Japan, warm conditions may be nd off the Canadian coast.

Recently Dodimead (1961b) discussed this Transitnal Domain and showed that in the eastern Subarcti it was furthest north in 1958 and 1959. At the sne time the area of divergence of the dynamic isoths at this level was furthest southward (see Circulan, p. 19). These are separate phenomena. The al result is that more warm water moved northward ng the British Columbia coast resulting in anomas conditions, both in the properties of the waters d the circulation along the British Columbia coast. 1959, the northward limit of the boundary was ilar to that in 1958; however, the area of diverce had shifted northward in 1959. Therefore, less rm water flowed northward in 1959 than in 1958. also suggested that an increase in the strength of northward subsurface flow (California Undercurnt) would result in warm water intruding at depth ng the British Columbia coast. Therefore, it is ssible that the variations in the position of this ansitional Domain may be generated, at least in rt, in the deeper sub-halocline waters. Evidently re are three dynamic causes of climate in the region division of the West Wind Drift.

There appears to have been a progressive eastward shift in the Western Subarctic Domain (Fig. 226 to 233), similar to the eastward shift of this domain in the upper zone. It reached its maximum eastward extent (long. 142°W.) in summer 1958 (Fig. 231) and remained in the same position during 1959. This water moves from the Bering Sea to the vicinity of the southern Kuril Islands and then principally eastward. It is warmed en route, finally mixing with the northward flowing waters in the Gulf of Alaska. From here, it moves westward in the Alaskan Stream; however, the characteristic temperature has been altered. In years when the Western Subarctic Domain appears to have its maximum eastward extent, its southern extent off the coast of Japan is least.

The seaward extent of the California Undercurrent also varies. It extended furthest offshore in 1959 and was confined to a very small area in 1956.

VIII. SUMMARY

This review describes:

(1) The Subarctic boundary. It extends across the ocean from Asia to America and is a recognizable boundary between the Subarctic and Subtropic waters.

(2) The Subarctic salinity structure. There is a permanent halocline maintained by an excess of precipitation over evaporation with a brackish upper zone above it, and a saline lower zone below. This feature defines the Subarctic Region and salmon water.

(3) Surface heating, cooling and wind-mixing processes and the consequent features of growth and decay of the seasonal thermocline. From these it is possible to assess and present the near-surface temperature structure, and assess the temperature in the upper zone during the previous winter from data observed during the summer.

(4) The circulation systems. The several currents and gyres have been named, as well as the relationship with the Subtropic circulation. Comparison of geostrophic transports from hydrographic data and wind stress transports from meteorological data show that there is a possibility of predicting the transport of water within specific areas.

(5) The concept of domains within the Subarctic Region. Domains are areas of consistent structure and oceanographic behaviour. This replaces the classical concept of water masses which are not definitive in the Subarctic.

The immensity of the field work that has been accomplished since 1955 should be obvious, and the fact that it is a particularly successful cooperative marine

investigation is unquestionable. As a result, this Region has advanced from one of the least known to one of the best known oceanic regions. It is also encouraging to point out field work has continued up to the time of this report, and further discoveries and refinements of our present knowledge can be expected in the near future. But perhaps equally important is the fact that extensive salmon fishing has been carried out during the course of these investigations, and that the results of the oceanographic work are beginning to shed some light on the distribution and migration of the salmons while in the oceanic environment.

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REFERENCES

Arons, A. B., and H. Stommel. 1956. A β-plane analysis of free periods of the second class in meridional and zonal oceans. *Deep Sea Res.*, 4: 23–31.

Barnes, C. A., and R. Paquette. 1954. Circulation near the Washington coast. *Univ. of Washington, Technical Report*, No. 17, 31 pp.

Barnes, Clifford A., and Thomas G. Thompson. 1938. Physical and chemical investigations in Bering Sea and portions of the North Pacific Ocean. *Univ. of Washington, Publ. in Oceanography*, 3(2): 35–79, and Appendix, pp. 1–64.

Bennett, E. B. 1959. Some oceanographic features of the northeast Pacific Ocean during August 1955. *J. Fish. Res. Bd. Canada*, 16(5): 565–633.

Bowden, K. F. 1958. Essay Review. Some recent studies of oceanic circulation. *J. du Conseil*, 23(3): 453–461.

Callaway, Richard J. 1960. Ocean circulation in the vicinity of the Aleutian Islands, 1957. Int. North Pacific Fish. Comm., Document No. 413, 27 pp., 55 figs.

Charney, J. G. 1955a. The Gulf Stream as an inertial boundary layer. *Proc. Nat. Acad. Sci.*, 41: 731–740.

Charney, J. G. 1955b. The generation of ocean currents by wind. *J. Mar. Res.*, 14: 477–498.

Dodimead, A. J. MS, 1958. Report on oceanographic investigations in the northeast Pacific Ocean during August 1956, February 1957, and August 1957. Fish. Res. Bd. Canada, MS Rept. Oceanogr. and Limnol. Series, No. 20, 10 pp.

Dodimead, A. J. MS, 1959. Atlas of physical and chemical data, North Pacific Surveys. January 20 to February 15, 1959. Fish. Res. Bd. Canada, MS Rept. Oceanogr. and Limnol. Series, No. 50, 3 pp., 40 figs.

Dodimead, A. J. MS, 1960. Atlas of oceanographic data. North Pacific Survey. January 12 to February 10, 19[illegible] Fish. Res. Bd. Canada, MS Rept. Oceanogr. and Limn[illegible] Series, No. 69, 4 pp., 45 figs.

Dodimead, A. J. 1961a. Some features of the upper zone[illegible] the sub-Arctic Pacific Ocean. *Bull. Int. North Pacific F[illegible] Comm.*, No. 3, pp. 11–24.

Dodimead, A. J. 1961b. The geostrophic circulation and [illegible] relation to the water characteristics in the northeast Pac[illegible] Ocean during the period 1955–60. *Abstracts of Sympos[illegible] Papers. Tenth Pac. Sci. Cong.*, Honolulu (1961), pp. 343.

Dodimead, A. J., and F. Favorite. MS, 1961. Oceanograp[illegible] atlas of the Pacific Subarctic Region. Summer 1958. F[illegible] Res. Bd. Canada, MS Rept. Oceanogr. and Limnol. Ser[illegible] No. 92, 6 pp., 40 figs.

Dodimead, A. J., and H. J. Hollister. 1958. Progress rep[illegible] of drift bottle releases in the northeast Pacific Ocean. [illegible] *Fish. Res. Bd. Canada*, 15(5): 851–865.

Dodimead, A. J., and H. J. Hollister. MS, 1962. D[illegible] bottle releases in the northeast Pacific Ocean. Fish I[illegible] Bd. Canada, MS Rept. Oceanogr. and Limnol. Series [illegible] press).

Doe, L. A. E. 1955. Offshore waters of the Canadian Pac[illegible] coast. *J. Fish Res. Bd. Canada*, 12(1): 1–34.

Favorite, Felix. 1961. Surface temperature and salinity [illegible] the Washington and British Columbia coasts, August, 1[illegible] and 1959. *J. Fish. Res. Bd. Canada*, 18(3): 311–319.

Favorite, Felix, and Mitchell G. Hanavan. 1960. Ocea[illegible] graphic conditions and salmon distribution south of the Ala[illegible] Peninsula and Aleutian Islands, 1956. Int. North Pac[illegible] Fish. Comm., Document No. 415, 34 pp.

Favorite, Felix, and James F. Hebard. 1961. Oceanograp[illegible] *Int. North Pacific Fish. Comm., Annual Report* 1960, pp. 81–[illegible]

Favorite, Felix, and Cuthbert M. Love. 1957. North[illegible] Pacific Ocean and Gulf of Alaska physical and chemical d[illegible] summer and fall 1955. *Univ. of Washington, Dept. of Ocea[illegible] raphy, Special Report*, No. 28, 88 pp.

Favorite, Felix, and B. A. Morse. 1962. Oceanograp[illegible] *Int. North Pacific Fish. Comm., Annual Report* 1961 (in press)

Favorite, Felix, and Glenn Pedersen. 1959. Bristol [illegible] Oceanography, August—September, 1938. *U.S. Fish [illegible] Wildlife Service, Special Scientific Report-Fisheries*, No. 311, 31 p[illegible]

Favorite, Felix, B. A. Morse, Alan H. Haselwood, [illegible] Robert A. Preston, Jr. 1962. North Pacific Ocean[illegible] raphy, February—April 1962. *U.S. Fish and Wildlife Ser[illegible] Special Scientific Report-Fisheries* (in press).

Favorite, Felix, John W. Schantz and Charles R. Heb[illegible] 1961. Oceanographic observations in Bristol Bay and [illegible] Bering Sea 1939–41 (U.S.C.G.T. *Redwing*). *U.S. Fish and Wi[illegible] life Service, Special Scientific Report-Fisheries*, No. 381, 323 pp.

Fleming, R. H. 1955. Review of oceanography of the north[illegible] Pacific. *Bull. Int. North Pacific Fish. Comm.*, No. 2, pp. 1–[illegible]

Fleming, R. H. 1958. Notes concerning the halocline in [illegible] northeastern Pacific Ocean. *J. Mar. Res.*, 17: 158–173

Fofonoff, N. P. MS, 1960a. Transport computations for [illegible] North Pacific Ocean, 1955. Fish. Res. Bd. Canada, [illegible] Rept. Oceanogr. and Limnol. Series, No. 77, 11 pp., 72 pla[illegible]

Fofonoff, N. P. MS, 1960b. Transport computations for [illegible] North Pacific Ocean, 1956. *Ibid.*, No. 78, 11 pp., 72 pla[illegible]

Fofonoff, N. P. MS, 1960c. Transport computations for [illegible] North Pacific Ocean, 1957. *Ibid.*, No. 79, 11 pp., 72 pl[illegible]

FOFONOFF, N. P. MS, 1960d. Transport computations for the North Pacific Ocean, 1958. *Ibid.*, No. 80, 11 pp., 72 plates.

FOFONOFF, N. P. MS, 1960e. Transport computations for the North Pacific Ocean, 1959. *Ibid.*, No. 81, 11 pp., 72 plates.

FOFONOFF, N. P. MS, 1961. Transport computations for the North Pacific Ocean, 1960. *Ibid.*, No. 93, 11 pp., 72 plates.

FOFONOFF, N. P. 1962a. Machine computations of mass transport in the North Pacific Ocean. *J. Fish. Res. Bd. Canada*, 19(5) (in press).

FOFONOFF, N. P. 1962b. Mass transport in the North Pacific. *Abstracts of Symposium Papers. Tenth Pac. Sci. Cong.*, Honolulu (1961), pp. 344.

FREEMAN, JR., J. C. 1954. Note on a prediction equation for the surface layer of a two-layer ocean. *Trans. American Geophys. Union*, 35 : 585–587.

FUKUOKA, J. 1955. The variation of the Polar Front in the sea adjacent to Japan. *Oceanogr. Mag. of Japan*, 6(4) : 181–195.

GIOVANDO, L. F. MS, 1962. The OCEAN system of assessment of bathythermograms. Fish. Res. Bd. Canada MS Rept. Oceanogr. and Limnol. Series, No. 105, 58 pp.

GOODMAN, J. R., J. H. LINCOLN, T. G. THOMPSON and F. A. ZEUSLER. 1942. Physical and chemical investigations: Bering Sea, Bering Strait, Chukchi Sea during the summers of 1937 and 1938. *Univ. of Washington, Publ. in Oceanography*, 3(4) : 105–169, and Appendix : 1–117.

GOODMAN, J. R., and THOMAS G. THOMPSON. 1940. Characteristics of the waters in sections from Dutch Harbor, Alaska to the Strait of Juan de Fuca and from the Strait of Juan de Fuca to Hawaii. *Univ. of Washington, Publ. in Oceanography*, 3(3) : 81–103, and Appendix : 1–48.

GRIER, M. C. 1941. Oceanography of the North Pacific Ocean, Bering Sea and Bering Strait: A contribution toward a bibliography. *Univ. of Washington, Publ. in Oceanography*, 2 : 290 pp.

HIDAKA, K. 1955. A theoretical study on the general circulation of the Pacific Ocean. *Pacific Science*, 9 : 183–200.

HIRANO, T. 1957a. The oceanographic study on the Subarctic region of the northwestern Pacific Ocean. Part I. *Bulletin Tokai Regional Fisheries Research Laboratory*, No. 15, pp. 39–55.

HIRANO, T. 1957b. The oceanographic study on the Subarctic region of the northwestern Pacific Ocean. Part II. *Ibid.*, No. 15, pp. 57–69.

HIRANO, T. 1958. The oceanographic study on the Subarctic region of the northwestern Pacific Ocean. Part III. *Ibid.*, No. 20, pp. 23–41.

HIRANO, T. 1961. The oceanographic study on the Subarctic region of the northwestern Pacific Ocean. Part IV. *Ibid.*, No. 29, pp. 11–39.

HAKODATE MARINE OBSERVATORY. 1961. On the drift bottles landed on Canada. *Umi, Marine Obs.*, No. 39, 196 pp.

HOLLISTER, H. J. MS, 1956. The program of bathythermograph observations at the Canadian Ocean Weather Station "Papa" (50°00'N, 145°00'W). MS Rept., Fish. Res. Bd. Canada, Joint Committee on Oceanography, 17 pp., 15 figs.

ICHIYE, T. 1955. On the possible origin of intermediate water in the Kuroshio. *Records of Oceanogr. Works in Japan*, 2(2) : 82–89.

INPFC. 1957. Annual Report for the year 1956. *Int. North Pacific Fish. Comm.*, 88 pp.

INPFC. 1958. Annual Report for the year 1957. *Int. North Pacific Fish. Comm.*, 86 pp.

INPFC. 1959. Annual Report for the year 1958. *Int. North Pacific Fish. Comm.*, 119 pp.

INPFC. 1960. Annual Report for the year 1959. *Int. North Pacific Fish. Comm.*, 116 pp.

JACOBS, W. C. 1951. The energy exchange between sea and atmosphere and some of its consequences. *Bull. Scripps Inst. of Oceanography*, Univ. of California, 6(2) : 27–122.

JAPAN AGRICULTURAL TECHNICAL ASSOCIATION. 1954. Oceanographic data in the northern waters of the North Pacific. 552 pp.

KAJIURA, K. 1949. On the hydrography of the Okhotsk Sea in summer. *J. Oceanogr. Soc. Japan*, 5(1) : 19–27.

KAWAII, H. 1955. On the polar frontal zone and its fluctuations in the waters to the northeast of Japan (1). *Bull. Tohoku Regional Fish. Res. Lab.*, 4 : 1–46.

KISHINDO, S. 1940a. On the bottom temperature and bottom current in the Pacific. *Hydro. Bull., Maritime Safety Agency.* 19th year, 8 : 259–270.

KISHINDO, S. 1940b. On the water stratification and the deep sea current in the Pacific. *Hydro. Bull., Maritime Safety Agency.* 19th year, 11 : 351–362.

KITANO, K. 1958. Oceanographic structure of the Bering Sea and the Aleutian waters. (Part 1. Based on the oceanogr. obs. by R. V. *Tenyo Maru*, 1957). (Part 2. Based on the oceanogr. obs. by the *Oshoro Maru*, *Komabashi*, *Iwate Maru* and *Soyo Maru* during 1956, 1936, 1935, 1934). *Bull. Hokkaido Reg. Fish. Res. Lab.*, 19 : 1–9 and 10–24.

KITANO, K. 1959. Oceanographic structure of the northern North Pacific Ocean. Int. North Pacific Fish. Comm., Document No. 310.

KOTO, H., and T. FUJII. 1958. Structure of the waters in the Bering Sea and the Aleutian region. *Bull. Faculty of Fish., Hokkaido Univ.*, 9(3) : 149–170.

LAFOND, E. C., and D. W. PRITCHARD. 1952. Physical oceanographic investigations in the eastern Bering and Chukchi Seas during the summer of 1947. *J. Mar. Res.*, 11(1–3) : 69–86.

LOVE, CUTHBERT M. 1956. Sources of oceanographic data for a portion of the North Pacific Ocean. Area : From 20° to 55°N and west coast of North America to 150°W. Years 1916–1954. *Univ. of Washington, Dept. of Oceanography, Special Report*, No. 25, 21 pp.

MASUZAWA, J. 1954. On the Kuroshio south of Shino-Misaki of Japan. *Oceanogr. Mag. of Japan*, 6(1) : 25–33.

MASUZAWA, J. 1955a. An outline of the Kuroshio in the eastern Sea of Japan. *Ibid.*, 7(1) : 29–48.

MASUZAWA, J. 1955b. Preliminary report on the Kuroshio in the eastern Sea of Japan. *Records of Oceanogr. Works in Japan*, 2(1) : 132–140.

MASUZAWA, J. 1956. On the cold belt along the northern edge of the Kuroshio. *Oceanogr. Mag. of Japan*, 8(2) : 151–156.

MASUZAWA, J. 1957. An example of cold eddies south of the Kuroshio. *Records of Oceanogr. Works in Japan*, 3(1) : 1–7.

MCEWEN, GEORGE F. 1912. The distribution of ocean temperatures along the west coast of North America deduced from Ekman's theory of the upwelling of cold waters from the adjacent ocean depths. *Intern. Revue geo. Hydrobiol. u. Hydrogr.*, Bd. 5 : 243–286.

McEwen, George F., Thomas G. Thompson and Richard Van Cleve. 1930. Hydrographic sections and calculated currents in the Gulf of Alaska, 1927 to 1928. *Rept. of Int. Fish. Comm.*, No. 4, pp. 5–36.

Mishima, S., and S. Nishizawa. 1955. Report on hydrographic investigations in the Aleutian waters and the southern Bering Sea in the early summer of 1953 and 1954. *Bull. Faculty of Fisheries, Hokkaido Univ.*, 6(2) : 85–124.

Morgan, G. W. 1956. On the wind-driven oceanic circulation. *Tellus*, 8 : 301–320.

Munk, W. H. 1950. On the wind-driven ocean circulation. *J. Meteorol.*, 1(2) : 79–93.

National Committee for the International Geophysical Year, Science Council of Japan. 1960. The results of the Japanese Oceanographic Project for the International Geophysical Year 1957/58, 198 pp.

Neumann, G. 1955. On the dynamics of wind-driven ocean currents. *Meteorol. Papers, New York Univ., College of Eng.*, 2(4) : 32 pp.

Oceanic Observations of the Pacific : 1955. 1960a. The NORPAC Atlas prepared by the NORPAC Committee. University of California Press and University of Tokyo Press, Berkeley and Tokyo. 118 plates.

Oceanic Observations of the Pacific : 1955. 1960b. The NORPAC Data prepared by the NORPAC Committee. University of California Press and University of Tokyo Press, Berkeley and Tokyo. 532 pp.

Ratmanoff, G. E. 1937. Explorations of the seas of Russia. *Publications of the Hydrological Institute, Leningrad*, No. 25 : 175 pp.

Reid, J. L. 1961. On the geostrophic flow at the surface of the Pacific Ocean with respect to the 1,000-decibar surface. *Tellus*, 13(4) : 489–502.

Robinson, Margaret K. 1957. Sea temperature in the Gulf of Alaska and in the northeast Pacific Ocean, 1941–1952. *Bull. Scripps Inst. of Oceanography*, 7(1) : 1–98, 61 figs.

Saito, Yukimasa. 1952. On the Oyashio Current (Part I) (A synthetic research on the oceanographical state of the North Pacific Ocean). *Journ. Inst. Poly., Osaka City Univ.*, 3(1) : 79–141.

Saur, J. F. T. 1958. Sources of time-series oceanographic and meteorological data of the Pacific Ocean. *U.S. Fish and Wildlife Service, Ocean Research Note*, No. 8, 36 pp.

Saur, J. F. T., and L. E. Eber. 1962. Monthly mean charts, sea surface temperature. North Pacific Ocean. *U.S. Fish and Wildlife Service, Circular*, 134, 36 plates.

Saur, J. F. T., R. M. Lesser, A. J. Carsola and W. M. Cameron. 1952. Oceanographic cruise to the Bering and Chukchi Seas, summer 1949. Part III : Physical observations and sound velocity in the deep Bering Sea. Report 298. U.S. Navy Electronics Laboratory, San Diego, California, 38 pp.

Saur, J. F. T , J. P. Tully and E. C. LaFond. MS, 1955. Oceanographic cruise to the Bering and Chukchi Seas, summer 1949. Part IV : Physical oceanographic studies. MS Rept., Fish. Res. Bd. Canada, Joint Committee on Oceanography. 31 pp.

Schott, G. 1935. Geographie des Indischen und Stillen Ozean. Table XXX von C Boysen. Hamburg.

Scripps Institution of Oceanography. 1957. *Oceanic Observations of the Pacific : 1949.* Univ. of Calif. Press, Berkeley Los Angeles. 363 pp.

Scripps Institution of Oceanography. 1960. *Oceanic Obs tions of the Pacific : 1950. Ibid.*, 508 pp.

Scripps Institution of Oceanography. 1961. *Oceanic Obs tions of the Pacific : Pre-1949. Ibid.*, 349 pp.

Shigematsu, R. 1933. On the current in the Sea of Okh and the origin of " Oyashio ". *The Hydrographic Bulletin,* year, No. 8, pp. 325–328.

Stommel, H. 1948. The westward intensification of w driven ocean currents. *Trans. American Geophys. Union*, 29 202–206.

Sugiura, J. 1957. On the Oyashio Current in the sea adja to Hokkaido. *Oceanogr. Mag. Japan*, 9(1) : 133–141.

Sverdrup, H. U. 1947. Wind-driven currents in a baroc ocean ; with applications to the equatorial currents of Eastern Pacific. *Proc. Nat. Acad. Sci.*, 33(11) : 318–32

Sverdrup, H. U., M. W. Johnson and R. H. Fleming. *The oceans : their physics, chemistry and general biology.* Prer Hall, Inc., New York, 1087 pp.

Tabata, S. 1961. Temporal changes of salinity, tempera and dissolved oxygen content of the water at Station in the northeast Pacific Ocean, and some of their determi factors. *J. Fish. Res. Bd. Canada*, 18(6) : 1073–1124.

Taguchi, K. 1959. On the surface currents in the mother fishing ground based on the recovery of drifting fl Fisheries Agency, pp. 1–70.

Takenouti, Y. 1960. The 1957–1958 oceanographic cha in the western Pacific. *California Cooperative Oceanic Fis Investigation Reports*, 17 : 67–76.

Thompson, Thomas G., George F. McEwen and Richard Cleve. 1936. Hydrographic sections and calculated rents in the Gulf of Alaska, 1929. *Rept. Int. Fish. Comm.* 10, 32 pp.

Thompson, William F., and Richard Van Cleve. 1936. History of the Pacific Halibut. (2) Distribution and life history. *Rept. Int. Fish. Comm.*, No. 9, 184 pp.

Tully, J. P. 1937. Oceanography of Nootka Sound. *J. Bd. Canada*, 3(1) : 43–69.

Tully, J. P. 1942. Surface non-tidal currents in the proaches to Juan de Fuca Strait. *J. Fish. Res. Bd. Ca* 5(4) : 398–409.

Tully, J. P. 1956. Some characteristics of sea water struc *Proc. 8th Pac. Sci. Congress*, Phillipines (1953), Vol. 3, pp. 662.

Tully, J. P., and F. G. Barber. 1960. An estuarine an in the Sub-arctic Pacific Ocean. *J. Fish. Res. Bd. Ca* 17(1) : 91–112.

Tully, J. P., and A. J. Dodimead. MS, 1957. Canadia anographic research in the northeast Pacific Ocean. Rept., Fish. Res. Bd. Canada, Pacific Oceanographic G 11 pp.

Tully, J. P., A. J. Dodimead and S. Tabata. 1960. An a alous increase of temperature in the ocean off the P Coast of Canada through 1957 to 1958. *J. Fish. Re Canada*, 17(1) : 61–80.

Tully, J. P., and L. F. Giovando. 1962. The seasonal th cline in the eastern Subarctic Pacific Ocean. Presen meeting of Royal Society of Canada, June, 1962 (in p

Uda, M. 1934. Normal monthly sea conditions in the

Sea, Yellow Sea and Okhotsk Sea. *J. Imp. Fish. Exptl. Stn., Tokyo*, 5 : 191–236.

UDA, M. 1935. The origin, movement and distribution of dichothermal water in the northeastern sea region of Japan. *Umi to Sora*, 15(12) : 445–452.

UDA, M. 1938. Hydrographical fluctuation in the northeastern sea region adjacent to Japan of the North Pacific Ocean. *J. Imp. Fish. Exptl. Stn., Tokyo*, 9 : 1–66.

UDA, M. 1949. On the correlated fluctuation of the Kuroshio current and cold water masses. *Oceanogr. Mag. Japan*, 1(1) : 1–12.

UDA, M. 1951. On the fluctuation of the main stream axis and its boundary line of Kuroshio. *J. Oceanogr. Soc. Japan*, 6(4) : 181–189.

UDA, M. 1955. Researches on the fluctuation of the North Pacific circulation. I. The fluctuation of Oyashio current in relation to the atmospheric circulation and to the distribution of dichothermal water masses in the North Pacific Ocean. *Records of Oceanogr. Works in Japan*, 2(2) : 43–55.

UDA, M. MS, 1959. Oceanographic Seminars. Fish. Res. Bd. Canada, MS Rept. Oceanogr. and Limnol. Series, No. 51, 110 pp.

UDA, M. 1960. On the fluctuation and prediction of ocean temperature in the North Pacific. *The Memoirs of the Kobe Marine Observatory*, Vol. 14.

UDA, M. 1962. Oceanography of the Subarctic Pacific Ocean. *J. Fish. Res. Bd. Canada* (in press).

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU. 1938. *Atlas of climatic charts of the oceans*. W.B. No. 1247, U.S. Government Printing Office, Washington, D.C., 130 charts.

U. S. NAVY HYDROGRAPHIC OFFICE. 1944a. World atlas of sea surface temperatures. *Publ. No.* 225, 48 plates.

U. S. NAVY HYDROGRAPHIC OFFICE. 1944b. Atlas of surface currents, northwestern Pacific Ocean. *Publ. No.* 569. 12 plates.

U.S. NAVY HYDROGRAPHIC OFFICE. 1947. Atlas of surface currents, northeastern Pacific Ocean. *Publ. No.* 570, 12 plates.

U.S. NAVY HYDROGRAPHIC OFFICE. 1953. References on the physical oceanography of the western Pacific Ocean. *Publ. No.* 238, 168 pp.

U.S. NAVY HYDROGRAPHIC OFFICE. 1958. Oceanographic survey results, Bering Sea area, winter and spring 1955. *Technical Report* 46, 95 pp.

VAUGHAN, THOMAS WAYLAND, and OTHERS. 1937. *International Aspects of Oceanography*. Nat. Acad. Sci., Washington, D.C., pp. 22–26.

VERONIS, G. 1956. Partition of energy between geostrophic and nongeostrophic oceanic motions. *Deep Sea Res.*, 3 : 157–177.

VERONIS, G., and G. W. MORGAN. 1955. A study of the time-dependent wind-driven ocean circulation in a homogeneous, rectangular ocean. *Tellus*, 7 : 232–242.

VERONIS, G., and H. STOMMEL. 1956. The action of variable wind stresses on a stratified ocean. *J. Mar. Res.*, 15 : 43–75.

WATANABE, N. 1954. A report on oceanographical investigations in the salmon fishing grounds of the North Pacific, 1952 and 1953. *Tokai Reg. Fish. Res. Lab., Special Publ.*, No. 3, pp. 1–5.

WATANABE, N. 1955. Hydrographic condition of the northwestern Pacific (Part I) On the temperature change of the upper layer in summer. *J. Oceanogr. Soc. Japan*, 11(3) : 111–122.

DATA SOURCES

Note: In those references where the name of the vessel was not mentioned, it has been inserted at the end of the reference; except for the 1955 data which are available in one volume.

1955:

Oceanic Observations of the Pacific: 1955. The NORPAC Data prepared by NORPAC Committee, University of California Press and University of Tokyo Press, Berkeley and Tokyo, 1960. 532 pp.

1956:

A. CANADA

Fisheries Research Board of Canada. 1957. Physical, Chemical and Plankton Data Record. North Pacific Survey, July 31—September 2, 1956. Appendix I. Marine Salmon Fishing Surveys, May 22—September 12, 1956. 191 pp. (H.M.C.S. *New Glasgow*).

Fisheries Research Board of Canada. 1957. Data Record, 1956. Ocean Weather Station " PAPA ", latitude 50°00′N, longitude 145°00′W. 122 pp. (C.C.G.S. *St. Catharines* and *Stonetown*).

B. JAPAN

Tokai Regional Fisheries Research Laboratory. 1957. Physical and Chemical Data, July 1—August 26, 1956. Unpublished (*Tenyo Maru*).

The Faculty of Fisheries, Hokkaido University. 1957. Data Record of Oceanographic Observations and Exploratory Fishing. No. 1, 247 pp. (*Oshoro Maru*).

Japanese Fisheries Agency. 1956. Japanese exploratory research fishing. Oceanographic Survey in 1956. Unpublished. (*Etsuzan Maru, Eiko Maru, Takuyo Maru*).

C. UNITED STATES OF AMERICA

Department of Oceanography, University of Washington, Seattle. 1957. Northeast Pacific Physical and Chemical Data, Summers of 1955 and 1956. Technical Report No. 55, 104 pp. (M.V. *Brown Bear* and *John N. Cobb*).

Department of Oceanography, University of Washington, Seattle. 1957. Physical and Chemical Data. Gulf of Alaska, Spring and Summer 1956 and Spring 1957. Technical Report No. 56, 90 pp. (M.V. *Brown Bear*).

Love, C.M. 1959. Physical and Chemical Data, North Pacific Ocean, Gulf of Alaska and Bering Sea, Summer of 1956. University of Washington, Department of Oceanography. Special Scientific Report No. 31. (M.V. *Celtic, Mitkof, Paragon* and *Tordenskjold*).

1957:

A. CANADA

Fisheries Research Board of Canada. 1958. Data Record. Ocean Weather Station " PAPA " (latitude 50°00′N, longitude 145°00′W), January 1, 1957—January 24, 1958. MS Rept. Oceanogr. and Limnol., No. 14, 261 pp. (C.C.G.S. *St. Catharines* and *Stonetown*).

Fisheries Research Board of Canada. 1957. Physical, Chemical

and Plankton Data Record. North Pacific Survey, January 23 to March 4, 1957. 110 pp. (H.M.C.S. *Oshawa*).
Fisheries Research Board of Canada. 1957. Physical, Chemical and Plankton Data Record. North Pacific Survey, July 23 to August 30, 1957. MS Rept. Oceanogr. and Limnol., No. 4, 103 pp. (H.M.C.S. *Oshawa*).
Manzer, J. I., and F. Neave. 1958. Data Record of Canadian Exploratory Fishing for Salmon in the Northeast Pacific in 1957. Fisheries Research Board of Canada. 298 pp. (M.V. *Key West II* and *Fort Ross*).

B. Japan

Japan Meteorological Agency. 1958. The Results of Marine Meteorological and Oceanographical Observations, July—December, 1957. No. 22, 183 pp. (*Ryofu Maru*).
Hokkaido Regional Fisheries Research Laboratory. 1958. A Preliminary Data of Physical Oceanography obtained Research Vessel "Tenyo-Maru" in the Bering Sea and the Aleutian Waters, July—August, 1957. 30 pp.
The Faculty of Fisheries, Hokkaido University. 1958. Data Record of Oceanographic Observations and Exploratory Fishing. No. 2, 199 pp. (*Oshoro Maru, Hokusei Maru*).
The Faculty of Fisheries, Hokkaido University. 1959. Data Record of Oceanographic Observations and Exploratory Fishing. No. 3, 296 pp. (*Oshoro Maru*).

C. United States of America

Favorite, Felix, and Glenn M. Pedersen. 1959. North Pacific and Bering Sea Oceanography, 1957. U.S. Fish and Wildlife Service, Special Scientific Report—Fisheries, No. 292, 106 pp. (M.V. *Attu, Pioneer* and *Paragon*).
Department of Oceanography, University of Washington. 1958. Cruise 176, M.V. "Brown Bear", July to September 1957 for the International Geophysical Year of 1957–58. Special Report No. 29.
Callaway, R. J., and J. W. McGary. Northeastern Pacific Albacore Survey. Part 2. Oceanographic and Meteorological Observations. Bureau of Commercial Fisheries, Honolulu. Special Scientific Report—Fisheries, No. 315, 133 pp. (M.V. *Hugh M. Smith*).

1958:

A. Canada

Fisheries Research Board of Canada. 1959. Data Record. Ocean Weather Station "P", latitude 50°N, longitude 145°W, July 9, 1958 to January 24, 1959. MS Rept. Oceanogr. and Limnol., No. 44. 104 pp. (C.C.G.S. *St. Catharines* and *Stonetown*).
Fisheries Research Board of Canada. 1958. Physical and Chemical Data Record, North Pacific Surveys, Continental Shelf and Gulf of Alaska, July 22 to August 16, 1958. MS Rept. Oceanogr. and Limnol., No. 29, 107 pp. (H.M.C.S. *Oshawa*).
Fisheries Research Board of Canada. 1958. Physical and Chemical Data Record, North Pacific Surveys, Western Aleutians and Bering Sea, June 27 to August 14, 1958. MS Rept. Oceanogr. and Limnol., No. 28, 104 pp. (C.N.A.V. *Whitethroat*).
Fisheries Research Board of Canada. 1959. Data Record. Ocean Weather Station "P", latitude 50°00′N, longitude 145°00′W, January 22—July 11, 1958. MS Rept. Oceanogr. and Limnol., No. 31, 112 pp. (C.C.G.S. *St. Catharines* and *Stonetown*).
Manzer, J. I., and F. Neave. 1959. Data Record of Canadi
Exploratory Fishing for Salmon in the Northeast Pacific in 19
Fisheries Research Board of Canada. 223 pp. (M.V. *Key W*
II and *Fort Ross*).
Fisheries Research Board of Canada. 1959. Oceanograp
Data Record, P.N.L. Surveys 1958. MS Rept. Oceanogr. a
Limnol., No. 49, 90 pp. (H.M.C.S. *Oshawa*).
Fisheries Research Board of Canada. 1958. Physical, Chemi
and Plankton Data Record, North Pacific Survey, March 11
April 10, 1958. MS Rept. Oceanogr. and Limnol., No.
220 pp. (H.M.C.S. *Oshawa*).

B. Japan

Japan Meteorological Agency. 1959. The Results of Mar
Meteorological and Oceanographic Observations, July—Dec
ber, 1958. No. 24, 289 pp. (*Ryofu Maru*).
The Faculty of Fisheries, Hokkaido University. 1959. D
Record of Oceanographic Observations and Exploratory Fishi
No. 3, 296 pp. (*Oshoro Maru, Hokusei Maru*).
Tokai Regional Fisheries Research Laboratory. 1959. I
Physical and Chemical Data by the R.V. "Soyo-Maru",
July—14 September 1958. 17 pp.

C. United States of America

Favorite, Felix, and Glenn M. Pedersen. 1959. North Pac
and Bering Sea Oceanography, 1958. U.S. Fish and Wil
Service. Special Scientific Report—Fisheries, No. 312, 230
(M.V. *Pioneer* and *Attu*).
Department of Oceanography, University of Washington. 19
Cruise 199, M.V. "Brown Bear", July to August, 1958 for
International Geophysical Year of 1957–1958. Special Re
No. 30.
Bureau of Commercial Fisheries, Honolulu. (Unpublish
(M.V. *Hugh M. Smith*).

1959:

A. Canada

Fisheries Research Board of Canada. 1959. Data Rec
North Pacific Survey, August 4 to September 1, 1959. MS R
Oceanogr. and Limnol., No. 54, 270 pp. (C.N.A.V. *Oshawa*
Whitethroat).
Fisheries Research Board of Canada. 1959. Physical
Chemical Data Record, North Pacific Surveys, January 2
February 15, 1959. MS Rept. Oceanogr. and Limnol., No
86 pp. (C.N.A.V. *Oshawa*).
Tabata, S., C. D. McAllister, D. G. Robertson, and H. J.
lister. 1960. Data Record. Ocean Weather Station "
latitude 50°00′N, longitude 145°00′W, January 21—Nove
24, 1959. Fisheries Research Board of Canada. MS R
Oceanogr. and Limnol., No. 59, 166 pp. (C.C.G.S. *St. Cath*
and *Stonetown*).

B. Japan

Japan Meteorological Agency. 1960. The Results of M
Meteorological and Oceanographical Observations, J
December, 1959. No. 26, 256 pp. (*Ryofu Maru*).
The Faculty of Fisheries, Hokkaido University. 1960.
Record of Oceanographic Observations and Exploratory Fis
No. 4, 221 pp. (*Oshoro Maru, Hokusei Maru*).

C. United States of America

ivorite, Felix, Richard J. Callaway, and James F. Hebard. 61. North Pacific and Bering Sea Oceanography, 1959. S. Fish and Wildlife Service, Special Scientific Report—sheries, No. 377, 212 pp. (M.V. *Pioneer* and *Tordenskjold*).

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FIGURE 173. Salinity at bottom of upper zone, winter 1959.
FIGURE 174. Salinity at bottom of upper zone, summer 1959.
FIGURE 175. Temperature at bottom of upper zone, summer 1955.
FIGURE 176. Temperature at bottom of upper zone, summer 1956.
FIGURE 177. Temperature at bottom of upper zone, winter 1957.
FIGURE 178. Temperature at bottom of upper zone, summer 1957.
FIGURE 179. Temperature at bottom of upper zone, winter 1958.
FIGURE 180. Temperature at bottom of upper zone, summer 1958.
FIGURE 181. Temperature at bottom of upper zone, winter 1959.
FIGURE 182. Temperature at bottom of upper zone, summer 1959.
FIGURE 183. Depth (metres) of surface of salinity=33.8‰, summer 1955.
FIGURE 184. Depth (metres) of surface of salinity=33.8‰, summer 1956.
FIGURE 185. Depth (metres) of surface of salinity=33.8‰, winter 1957.
FIGURE 186. Depth (metres) of surface of salinity=33.8‰, summer 1957.
FIGURE 187. Depth (metres) of surface of salinity=33.8‰, winter 1958.
FIGURE 188. Depth (metres) of surface of salinity=33.8‰, summer 1958.
FIGURE 189. Depth (metres) of surface of salinity=33.8‰, winter 1959.
FIGURE 190. Depth (metres) of surface of salinity=33.8‰, summer 1959.
FIGURE 191. Temperature on the surface of salinity=33.8‰, summer 1955.
FIGURE 192. Temperature on the surface of salinity=33.8‰, summer 1956.
FIGURE 193. Temperature on the surface of salinity=33.8‰, winter 1957.

FIGURE 194. Temperature on the surface of salinity=33.8‰, summer 1957.
FIGURE 195. Temperature on the surface of salinity=33.8‰, winter 1958.
FIGURE 196. Temperature on the surface of salinity=33.8‰, summer 1958.
FIGURE 197. Temperature on the surface of salinity=33.8‰, winter 1959.
FIGURE 198. Temperature on the surface of salinity=33.8‰, summer 1959.
FIGURE 199. Depth (metres) of surface of salinity=34.0‰, summer 1955.
FIGURE 200. Depth (metres) of surface of salinity=34.0‰, summer 1956.
FIGURE 201. Depth (metres) of surface of salinity=34.0‰, winter 1957.
FIGURE 202. Depth (metres) of surface of salinity=34.0‰, summer 1957.
FIGURE 203. Depth (metres) of surface of salinity=34.0‰, winter 1958.
FIGURE 204. Depth (metres) of surface of salinity=34.0‰, summer 1958.
FIGURE 205. Depth (metres) of surface of salinity=34.0‰, winter 1959.
FIGURE 206. Depth (metres) of surface of salinity=34.0‰, summer 1959.
FIGURE 207. Temperature on the surface of salinity=34.0‰, summer 1955.
FIGURE 208. Temperature on the surface of salinity=34.0‰, summer 1956.
FIGURE 209. Temperature on the surface of salinity=34.0‰, winter 1957.
FIGURE 210. Temperature on the surface of salinity=34.0‰, summer 1957.
FIGURE 211. Temperature on the surface of salinity=34.0‰, winter 1958.
FIGURE 212. Temperature on the surface of salinity=34.0‰, summer 1958.
FIGURE 213. Temperature on the surface of salinity=34.0‰, winter 1959.
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FIGURE 216. Schematic diagram of upper zone domains.
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FIGURE 218. Upper zone domains, summer 1956.
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FIGURE 220. Upper zone domains, summer 1957.
FIGURE 221. Upper zone domains, winter 1958.
FIGURE 222. Upper zone domains, summer 1958.
FIGURE 223. Upper zone domains, winter 1959.
FIGURE 224. Upper zone domains, summer 1959.
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FIGURE 228. Lower zone domains, winter 1957.
FIGURE 229. Lower zone domains, summer 1957.
FIGURE 230. Lower zone domains, winter 1958.
FIGURE 231. Lower zone domains, summer 1958.
FIGURE 232. Lower zone domains, winter 1959.
FIGURE 233. Lower zone domains, summer 1959.

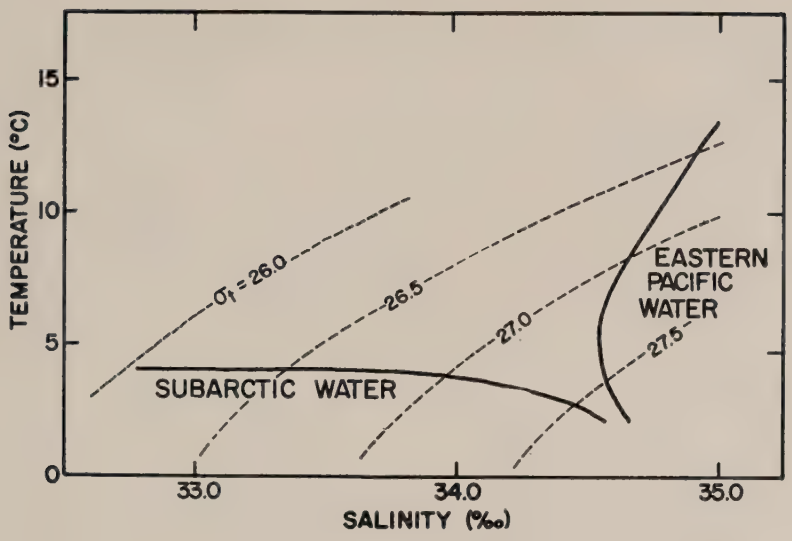


FIGURE 1. Representative T-S curves of Subarctic and Eastern Pacific Waters.

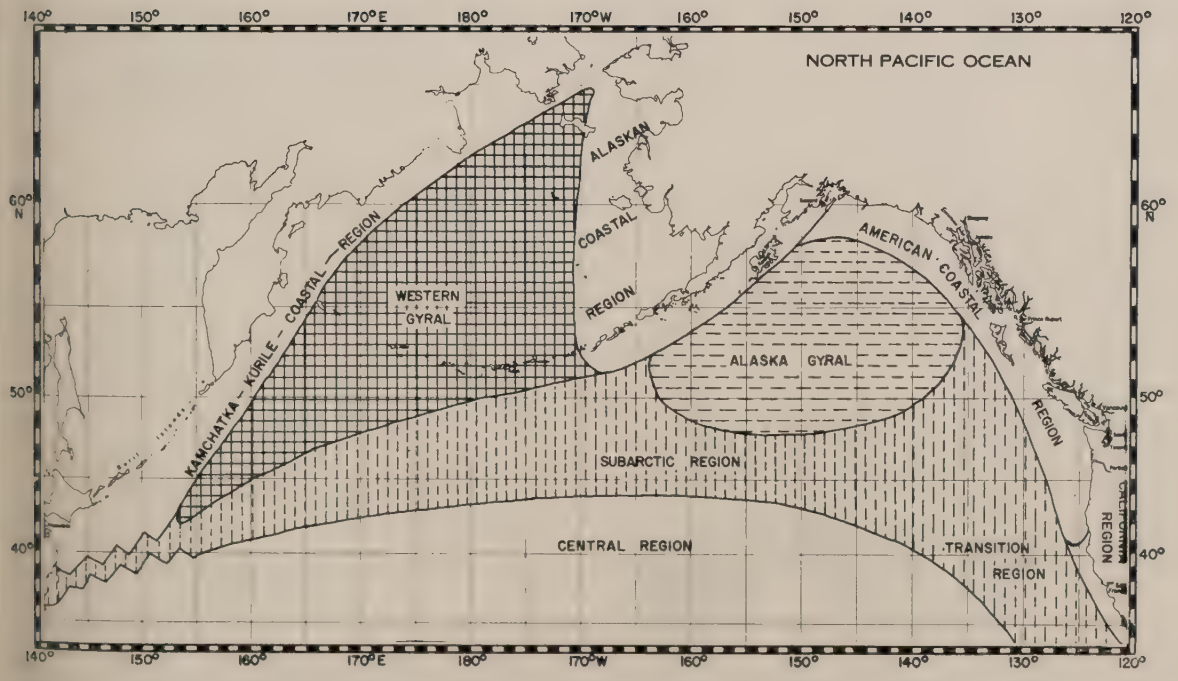


FIGURE 2. Regions and zones in the northern Pacific (adapted from Fleming, 1955).

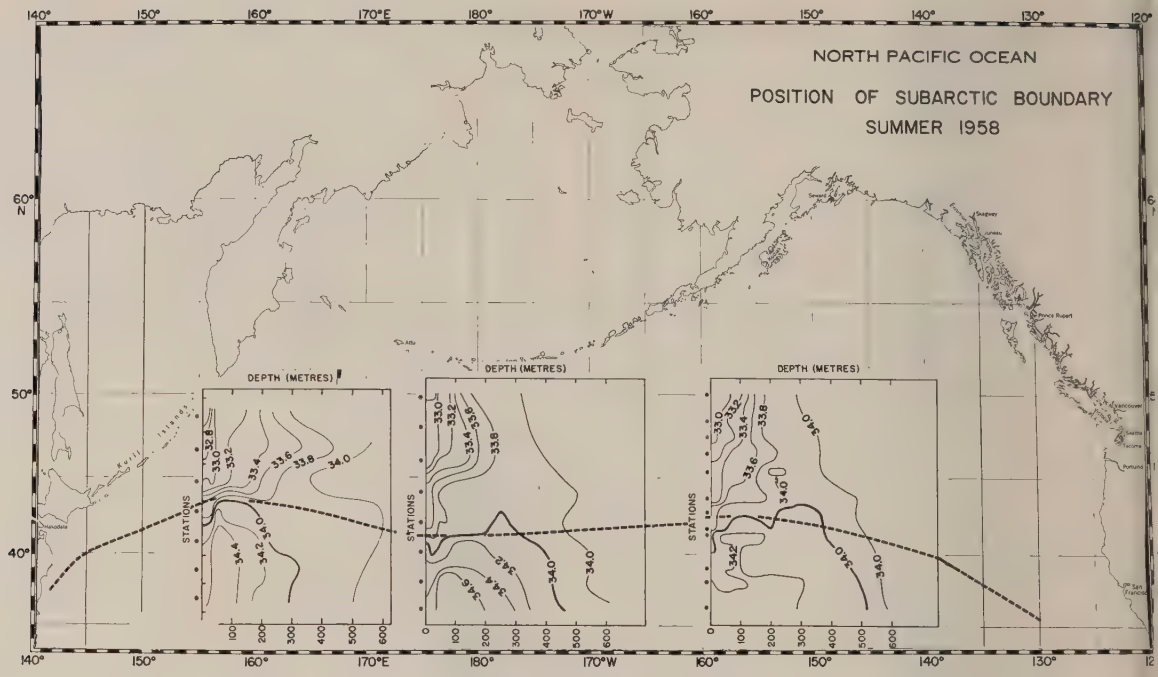


FIGURE 3. Position of Subarctic boundary during summer 1958.

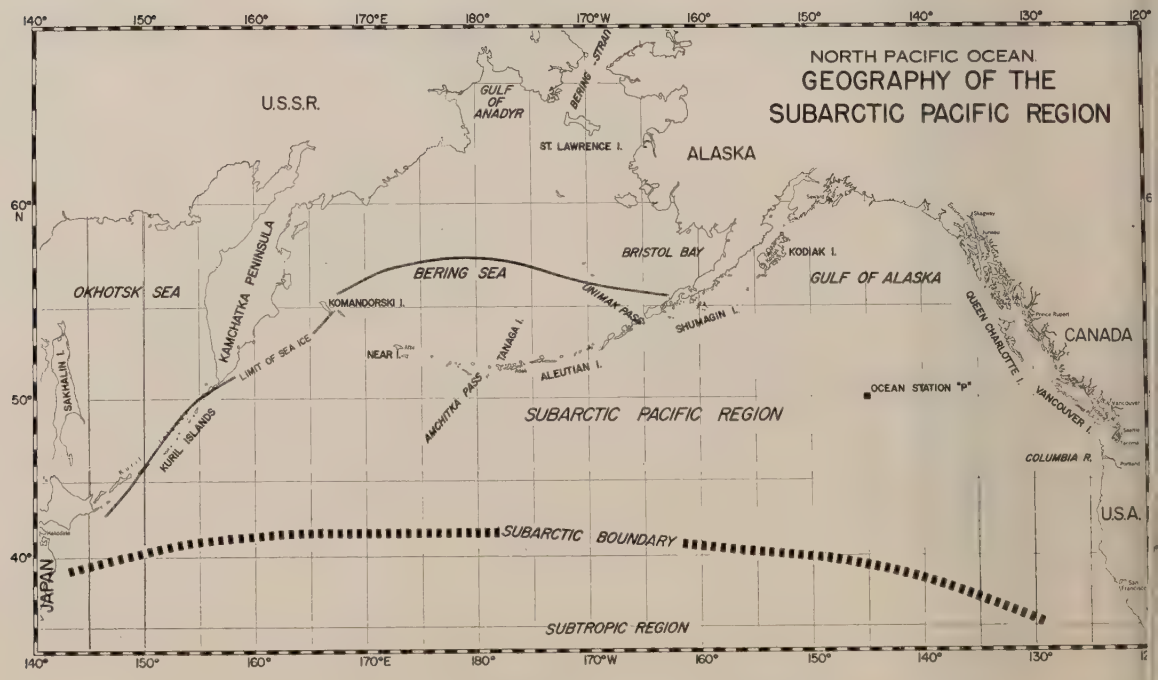


FIGURE 4. Geography of Subarctic Pacific Region.

FIGURE 5. Bathymetry (metres).

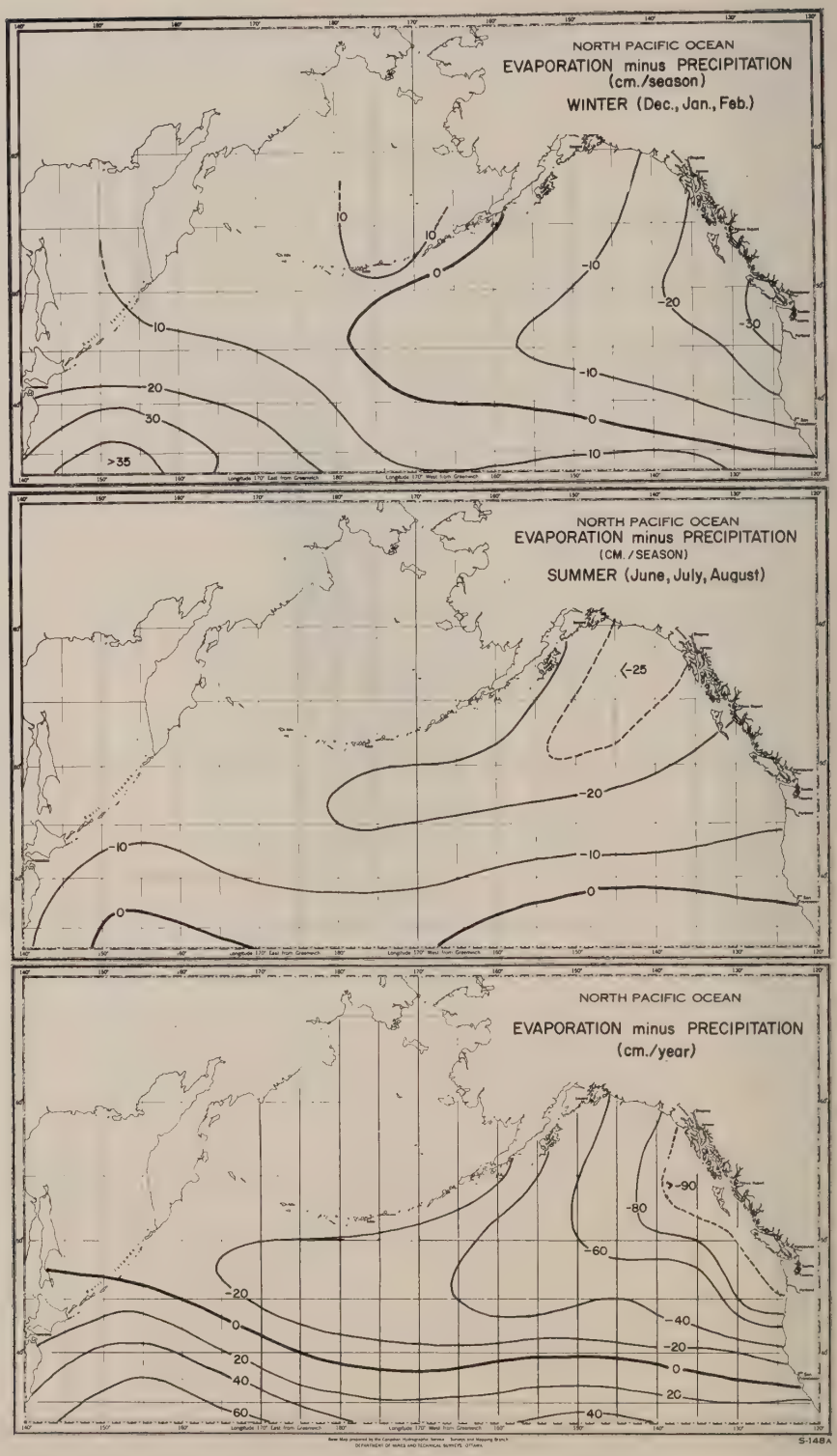


FIGURE 6. Evaporation minus precipitation—winter, summer and annual conditions (adapted from Jacobs, 1951).

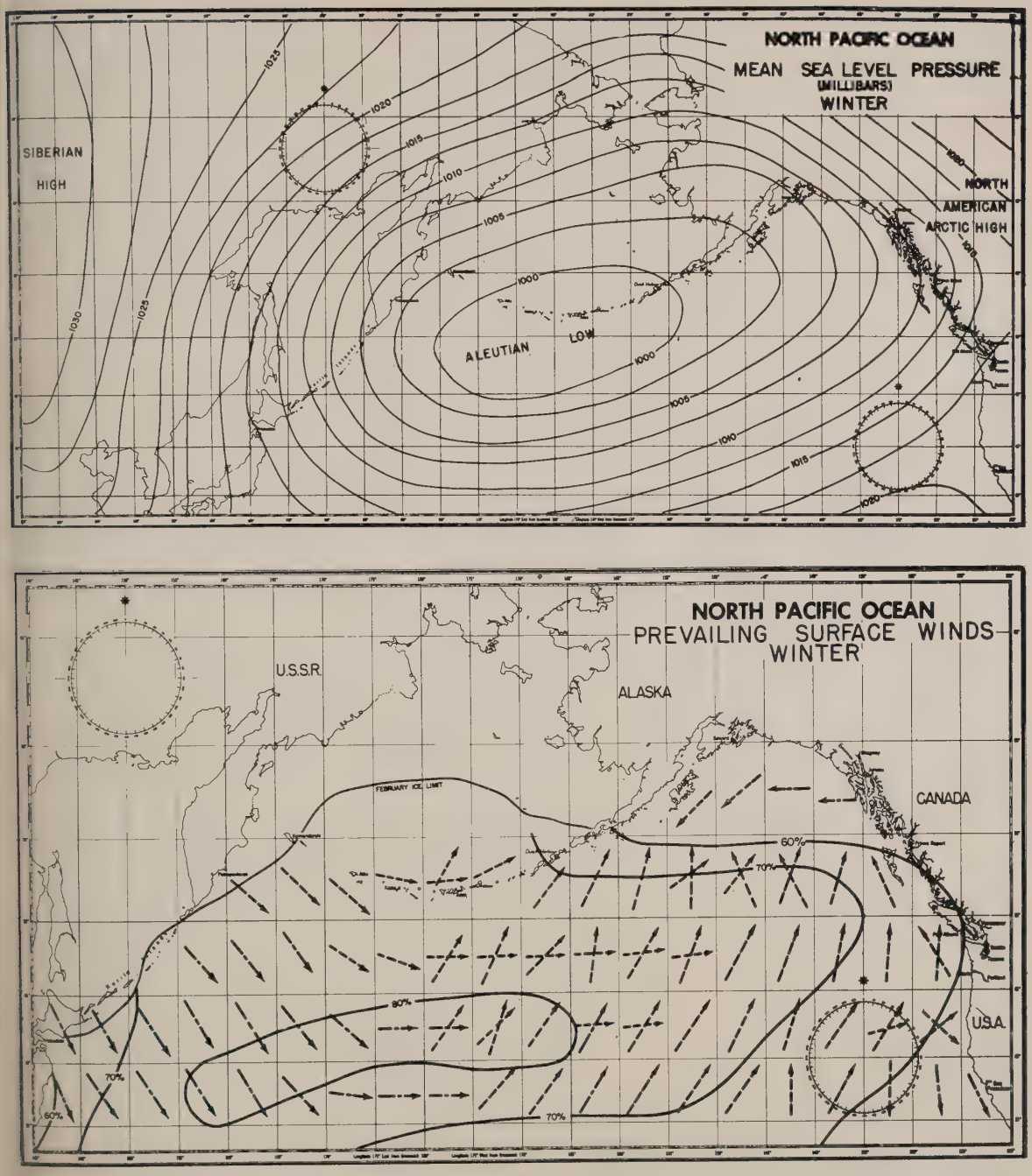
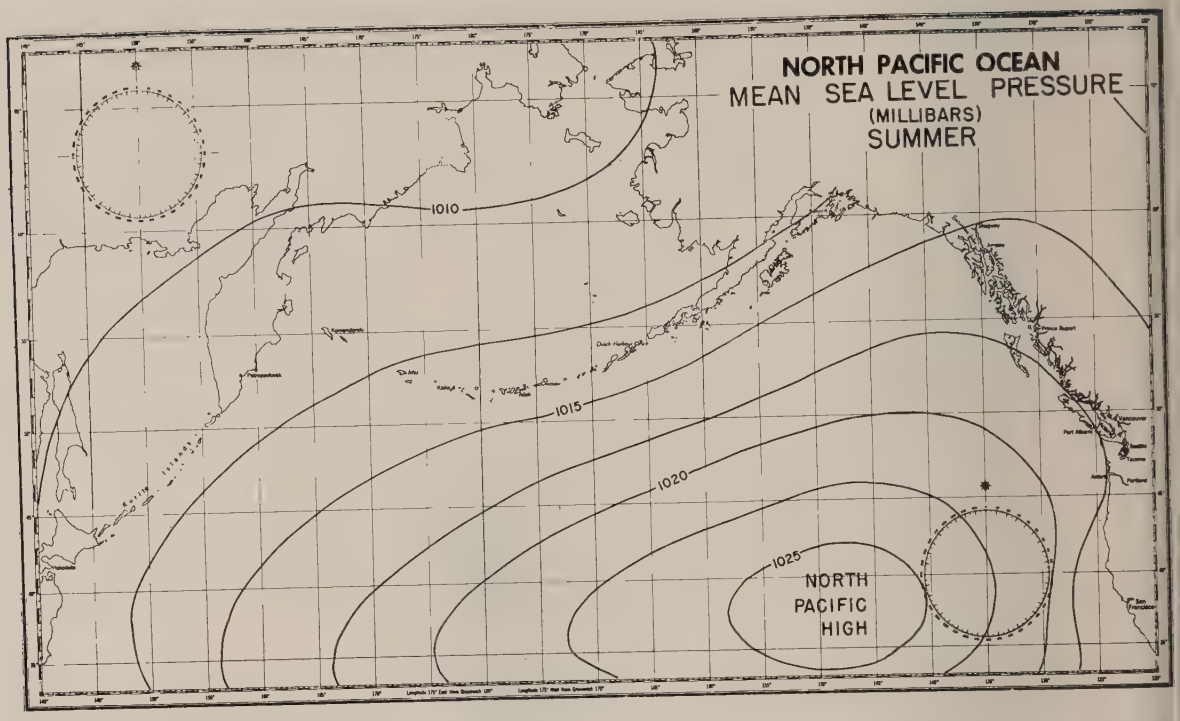


FIGURE 7. Mean sea level pressure (millibars) and prevailing surface winds during winter (contours indicate the percentage of time the winds are Force 3 and less).



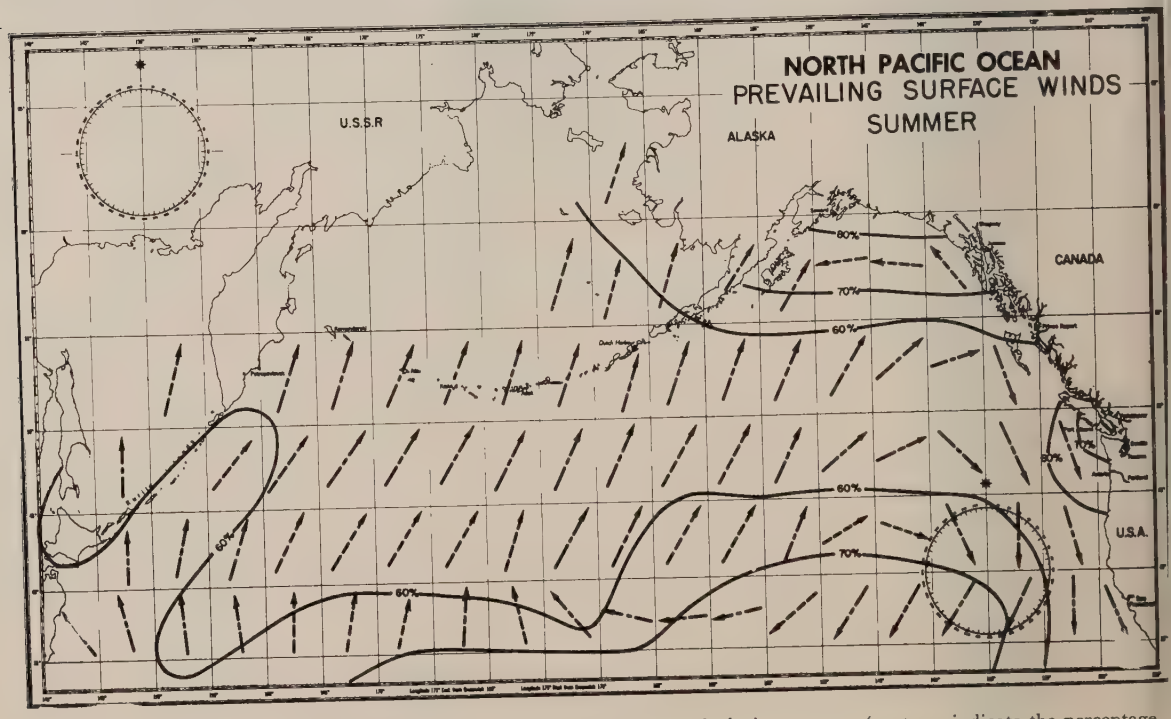


FIGURE 8. Mean sea level pressure (millibars) and prevailing surface winds during summer (contours indicate the percentage of time the winds are Force 3 and less).

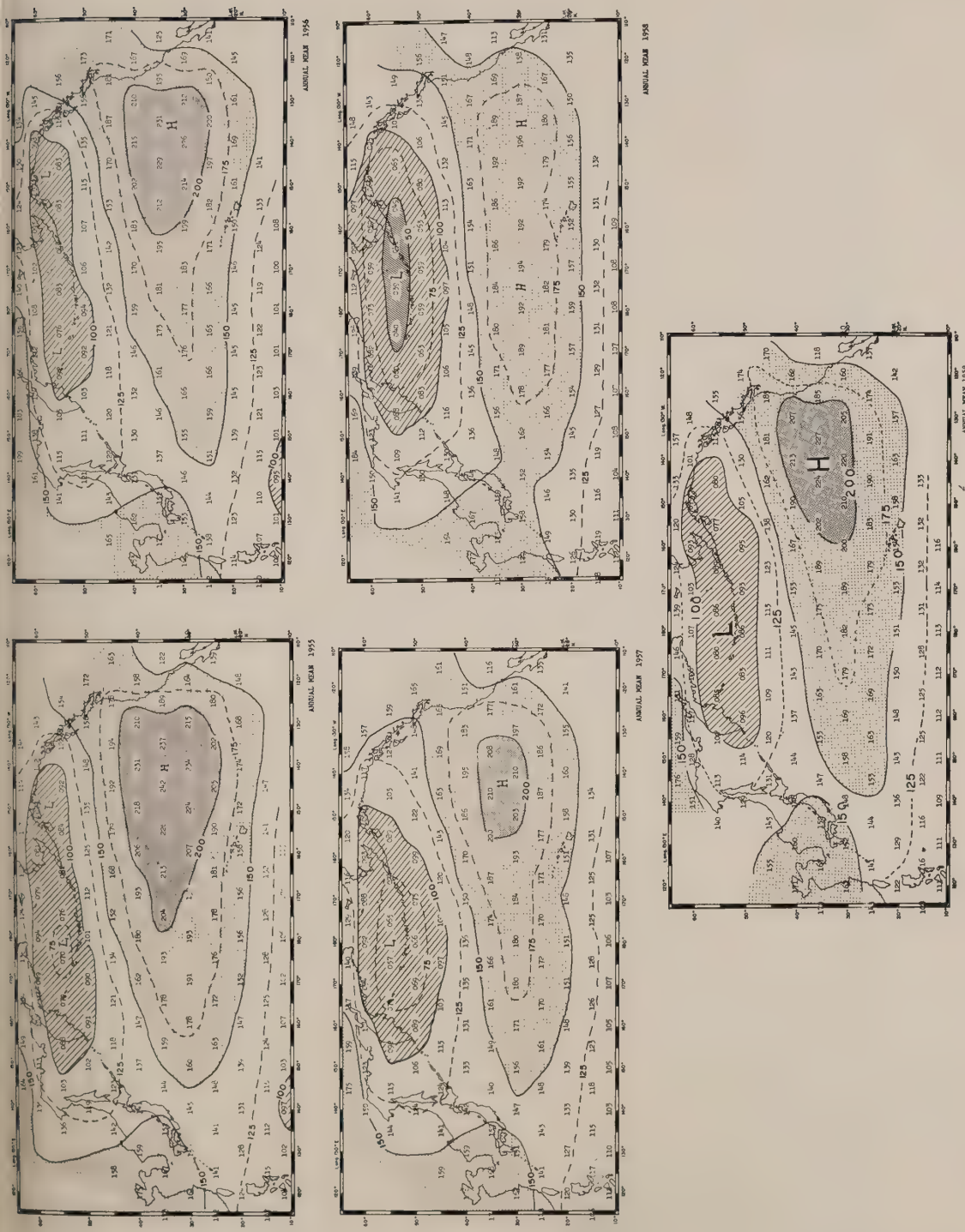


FIGURE 9. Annual mean sea level pressure, 1955 to 1959.

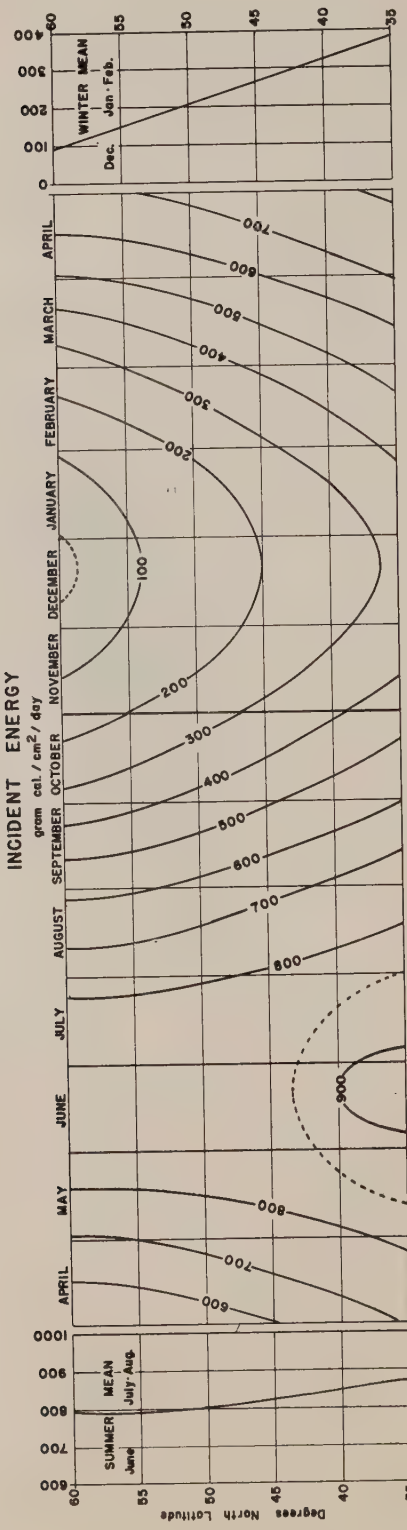


FIGURE 10. Annual cycle of incident energy (gram cal/cm²/day) from lat. 35°N. to 60°N. (Tully and Dodimead, 1957).

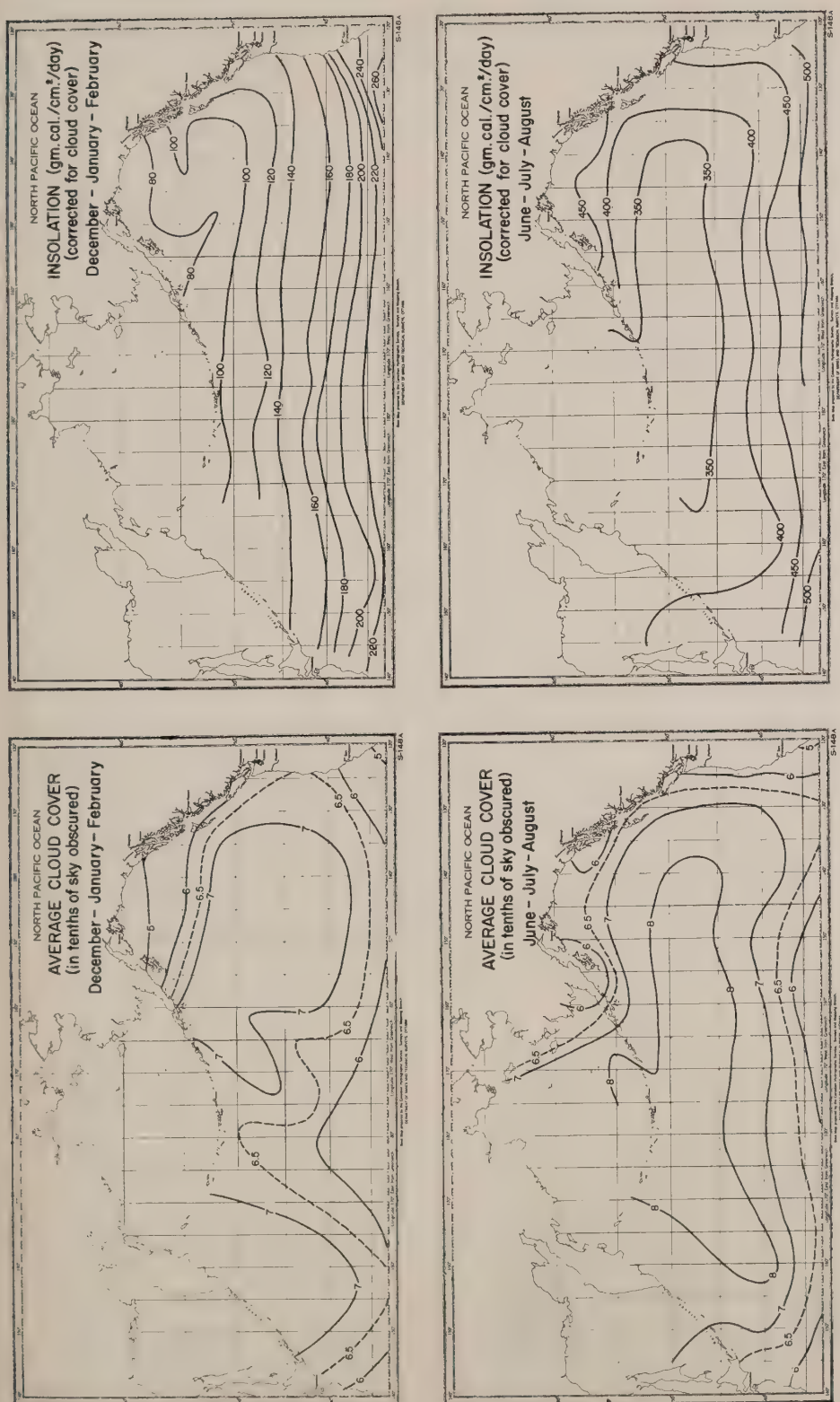
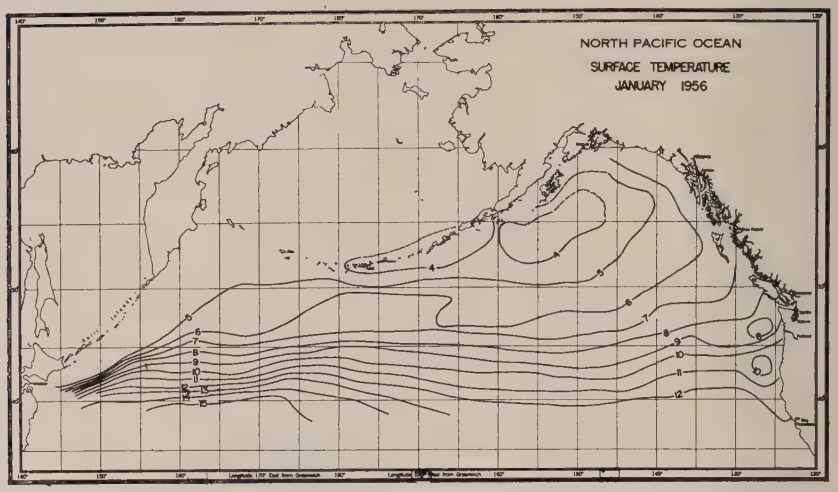
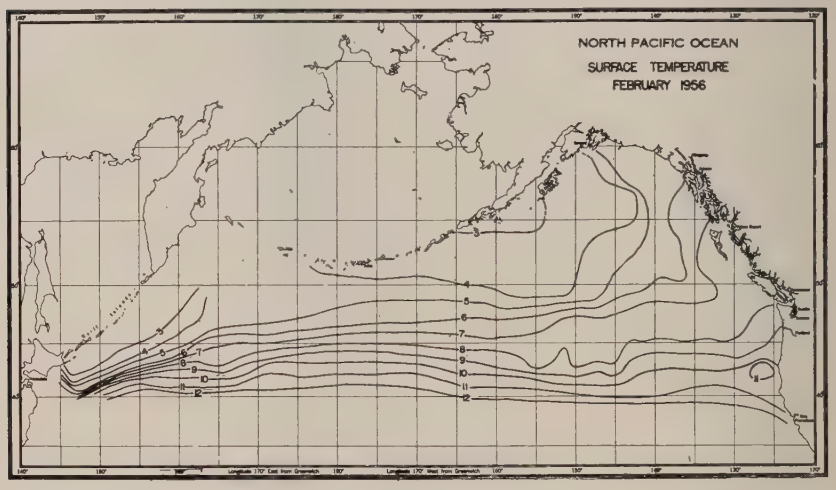


FIGURE 11. Average cloud cover and insolation during winter and summer.





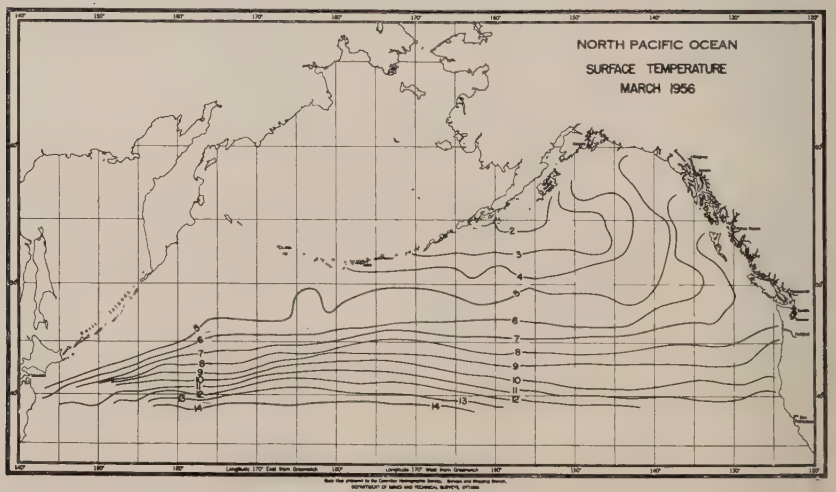
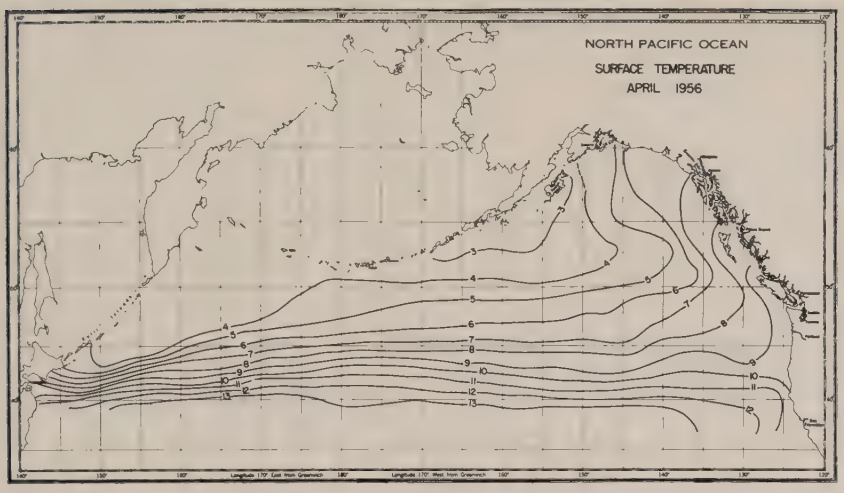
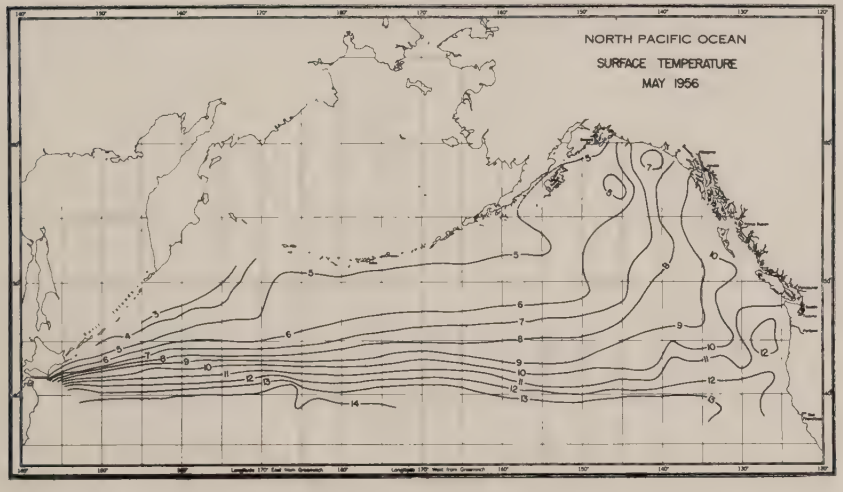


FIGURE 12a. Monthly mean sea surface temperature charts, January, February, March, 1956 (adapted from Saur and Eber, 1962).





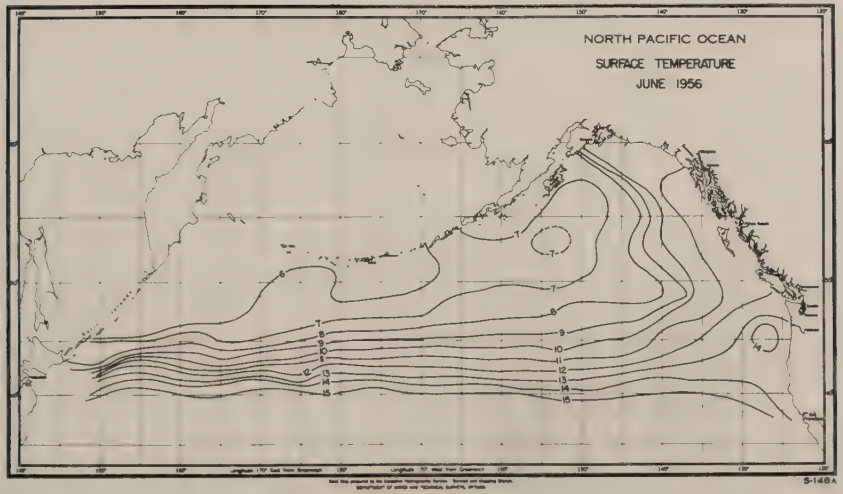


FIGURE 12b. Monthly mean sea surface temperature charts, April, May, June, 1956 (adapted from Saur and Eber, 1962).

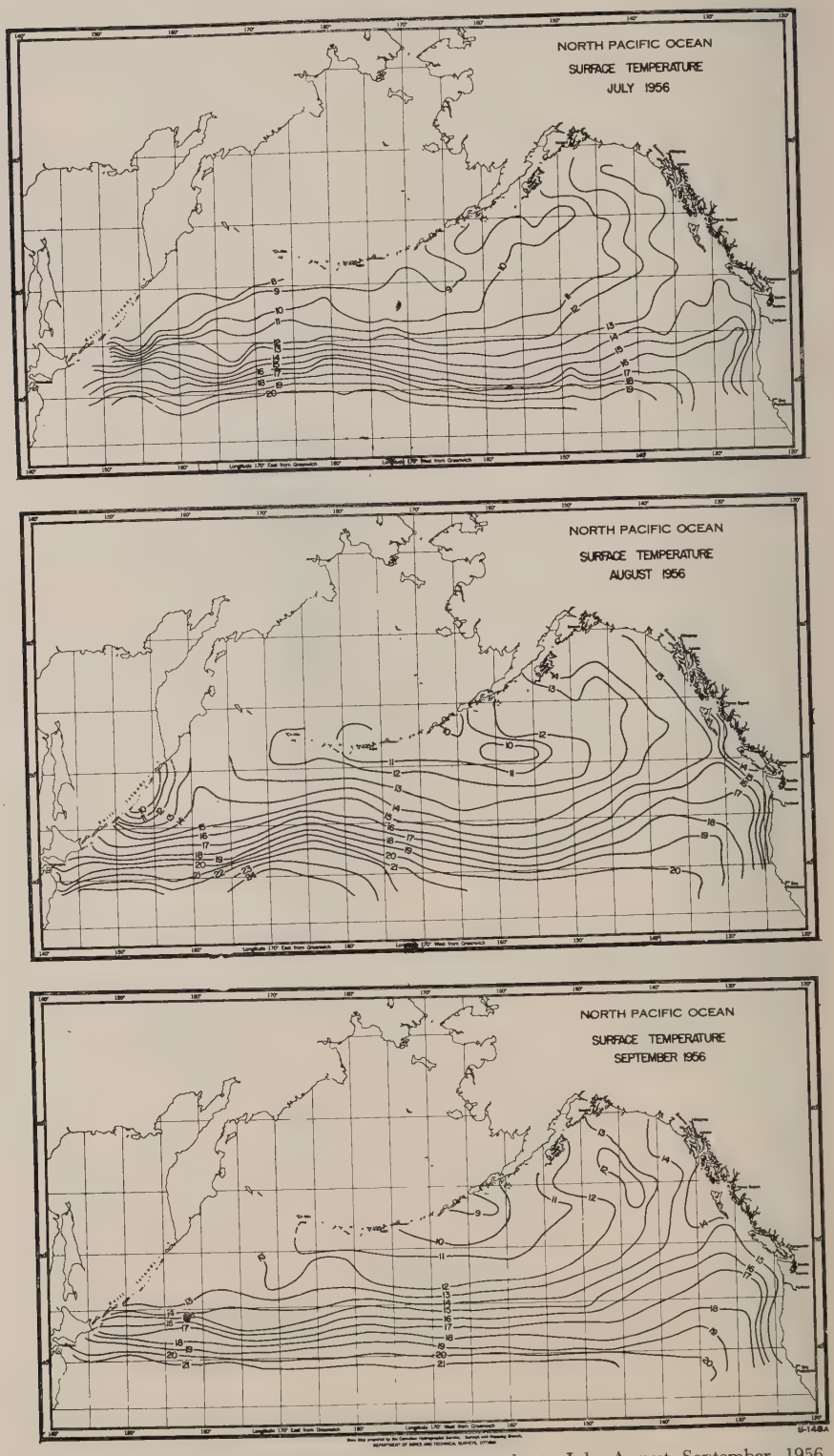


FIGURE 12c. Monthly mean sea surface temperature charts, July, August, September, 1956 (adapted from Saur and Eber, 1962).

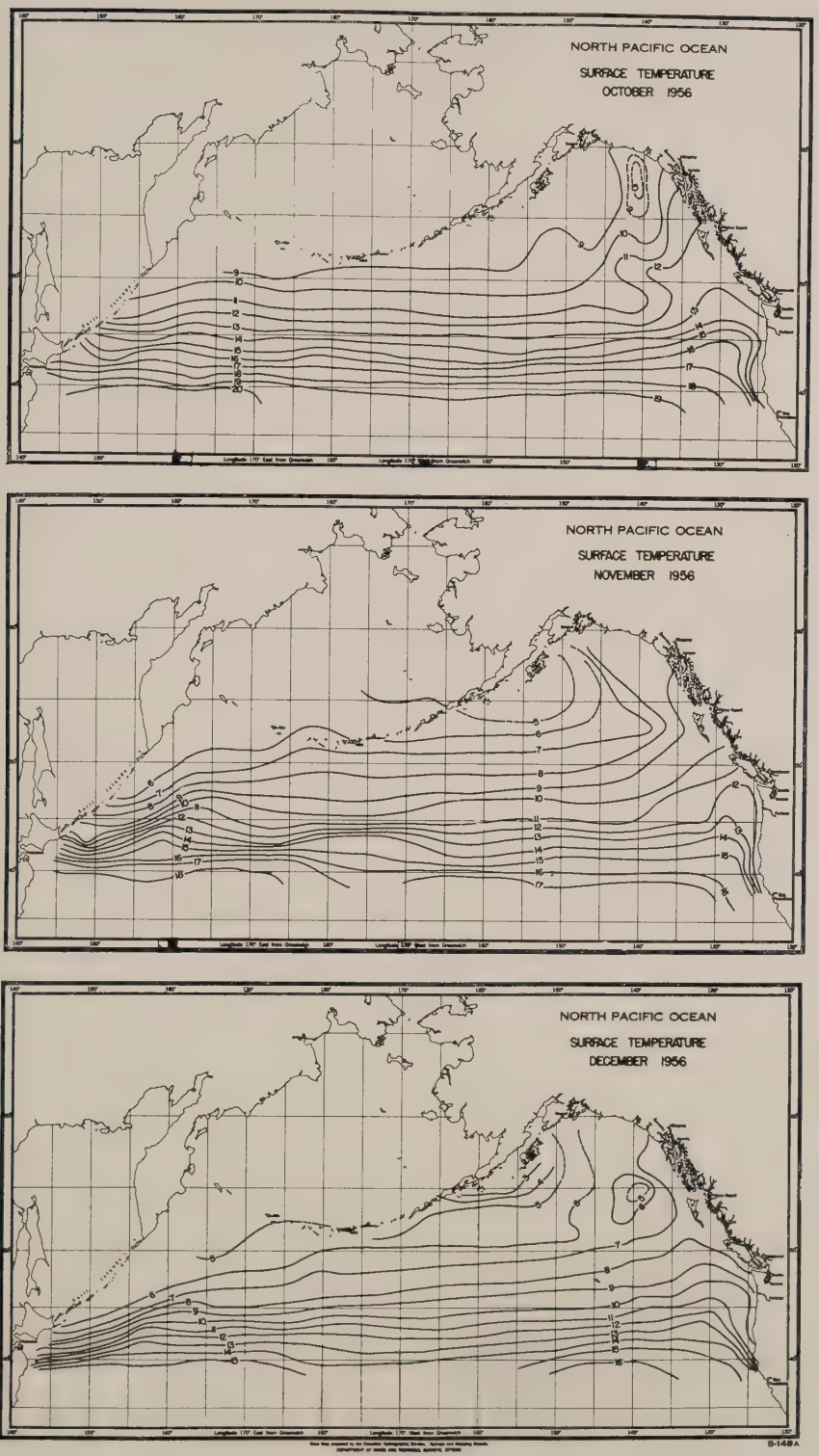


FIGURE 12d. Monthly mean sea surface temperature charts, October, November, December, 1956 (adapted from Saur and Eber, 1962).

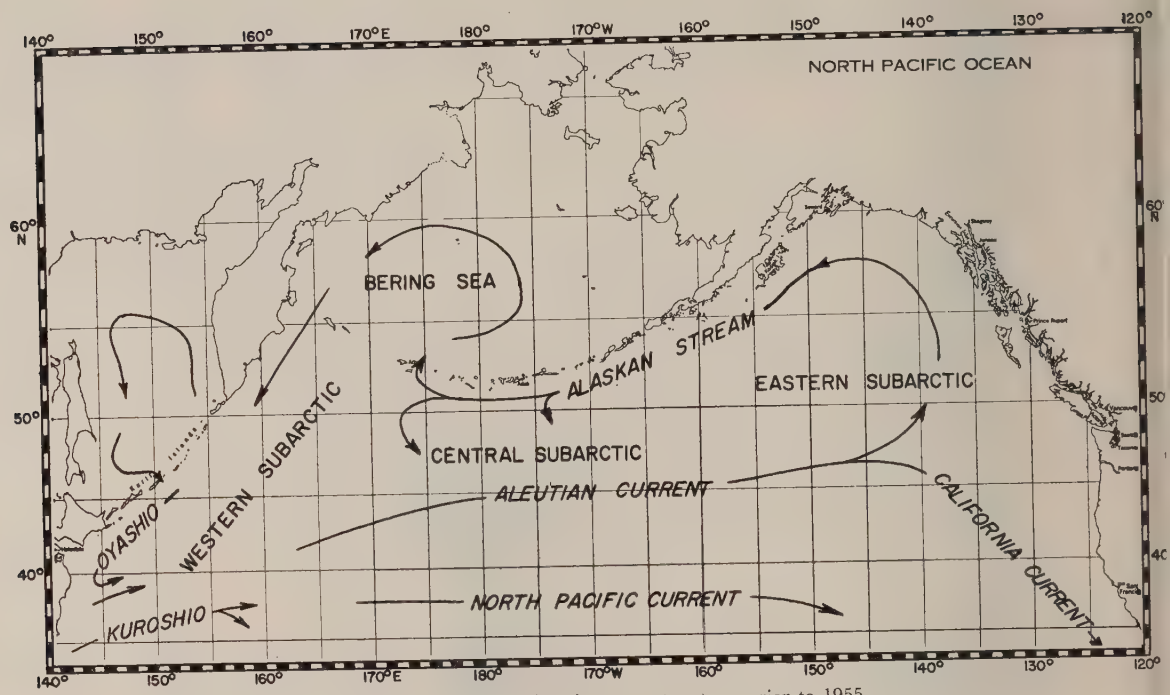


FIGURE 13. Recognized major current systems prior to 1955.

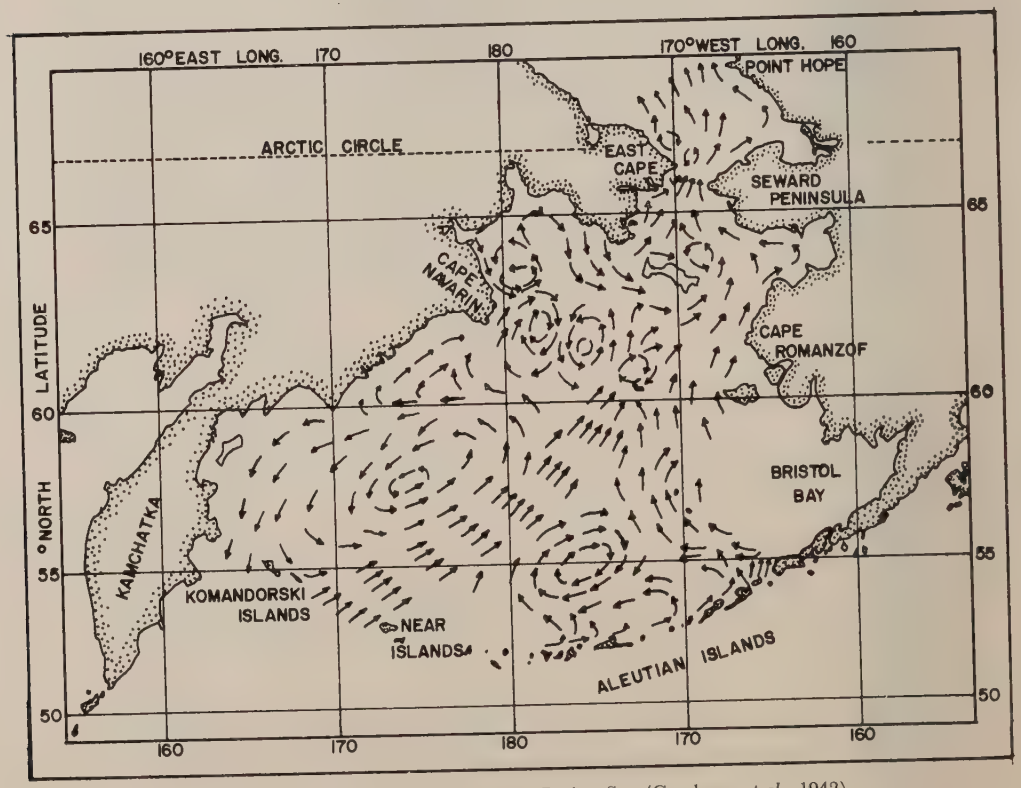


FIGURE 14. Surface circulation in the Bering Sea (Goodman *et al.*, 1942).

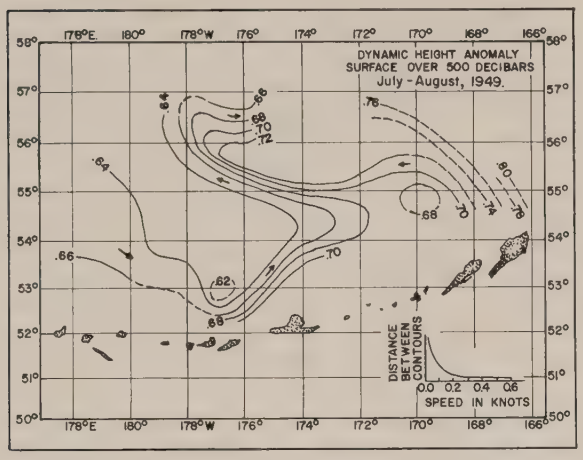

DYNAMIC HEIGHT ANOMALY
SURFACE OVER 500 DECIBARS
July - August, 1949.
DISTANCE BETWEEN CONTOURS
0.0 0.2 0.4 0.6
SPEED IN KNOTS
178°E 180° 178°W 176° 174° 172° 170° 168° 166°
58° 57° 56° 55° 54° 53° 52° 51° 50°

FIGURE 15. Dynamic height anomaly, surface over 500 decibars, Bering Sea, July-August 1949 (Saur *et al.*, 1952).

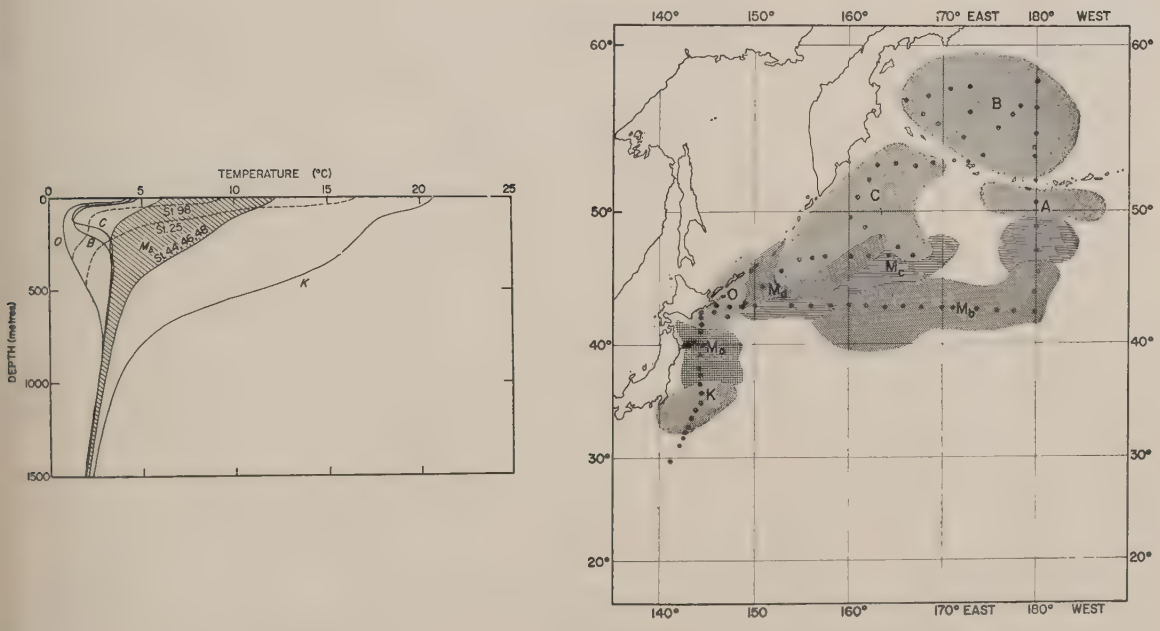


FIGURE 16. Vertical temperature curves of typical water systems and their regional distributions in the western Subarctic Region (Hirano, 1957a).

Left: Vertical temperature curves of typical water systems based on data from the R.V. *Tenyo Maru*, 1954 (Hirano, 1957a). K: Kuroshio water, O: Okhotsk water, B: Bering water, C: central water of the western Subarctic Region, M_b: Mixing water between the Kuroshio and the Okhotsk water. The right edge of M_b shows the curve at sts. 44, 46 and 48, approximately. Curves in broken line show the water in the mixing region M_a at sts. 25 and 98.

Right: Regional distributions of water systems in the western Subarctic Region based on data from the R.V. *Tenyo Maru*, 1954 (Hirano, 1957a). A: water originating from the Gulf of Alaska, M_a: water in the mixing region off the Sanriku, M_c: mixing water between the central water of the western Subarctic Region and the mixing water M_b, M_d: mixing water between the Okhotsk water and the central water of the western Subarctic Region.

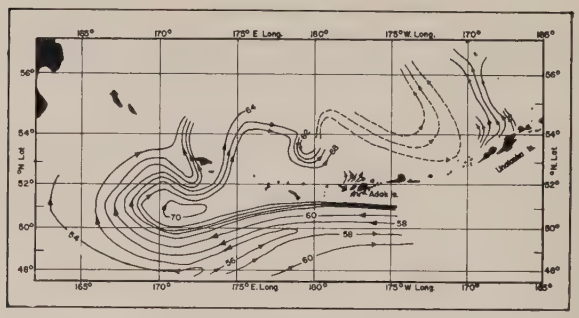


FIGURE 17. Geopotential topography, 100/750 decibars near the Aleutian Islands (Mishima and Nishizawa, 1955).

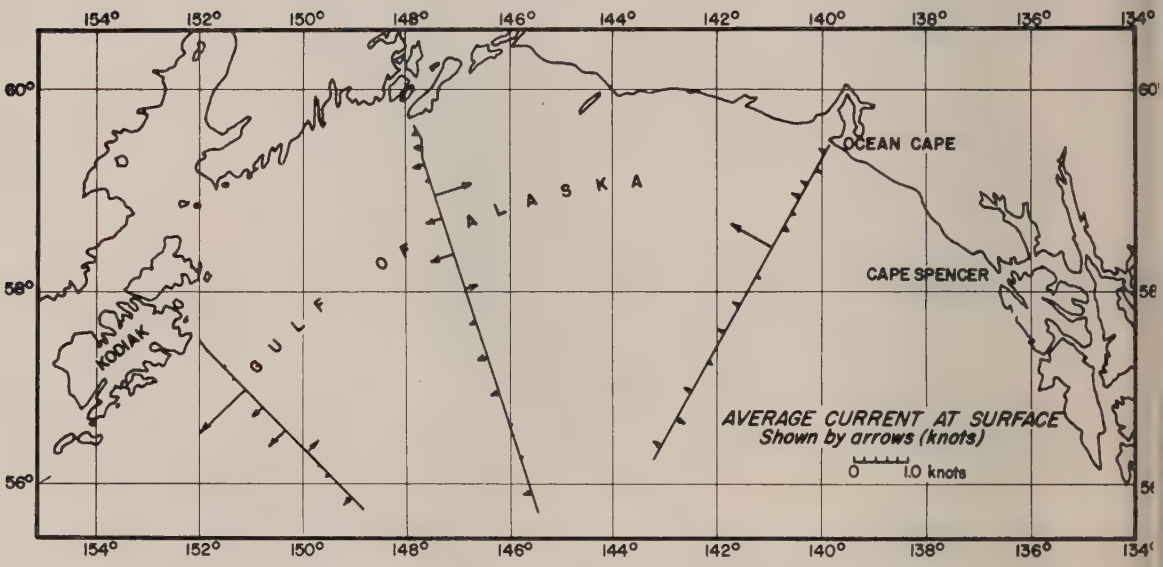


FIGURE 18. Calculated surface currents relative to bottom in Gulf of Alaska (Thompson *et al.*, 1936).

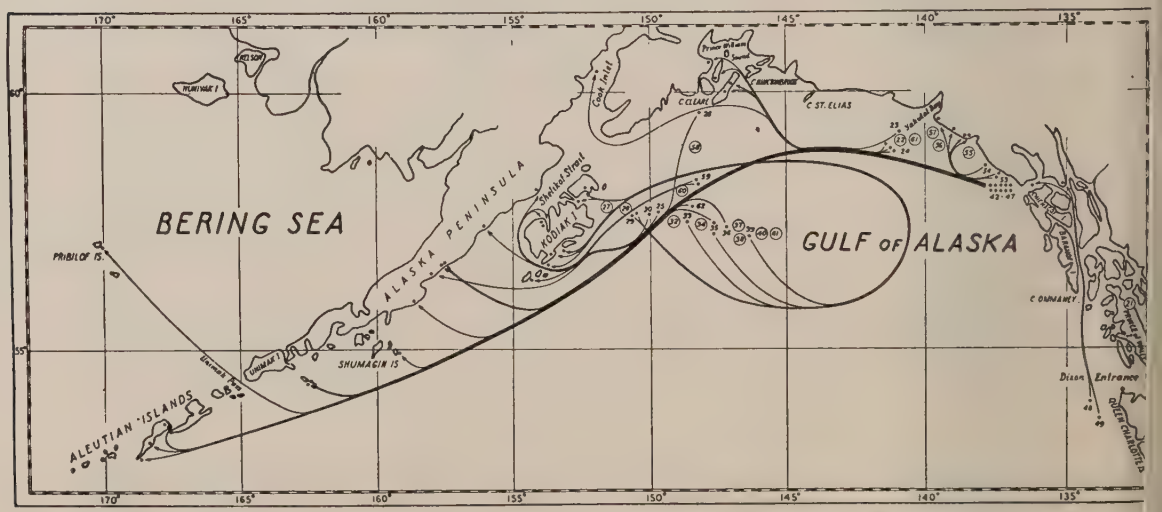


FIGURE 19. Returns from drift bottles released between January 3 and March 7, 1933, and January 9 and February 25, 193 (Thomposn and Van Cleve, 1936).

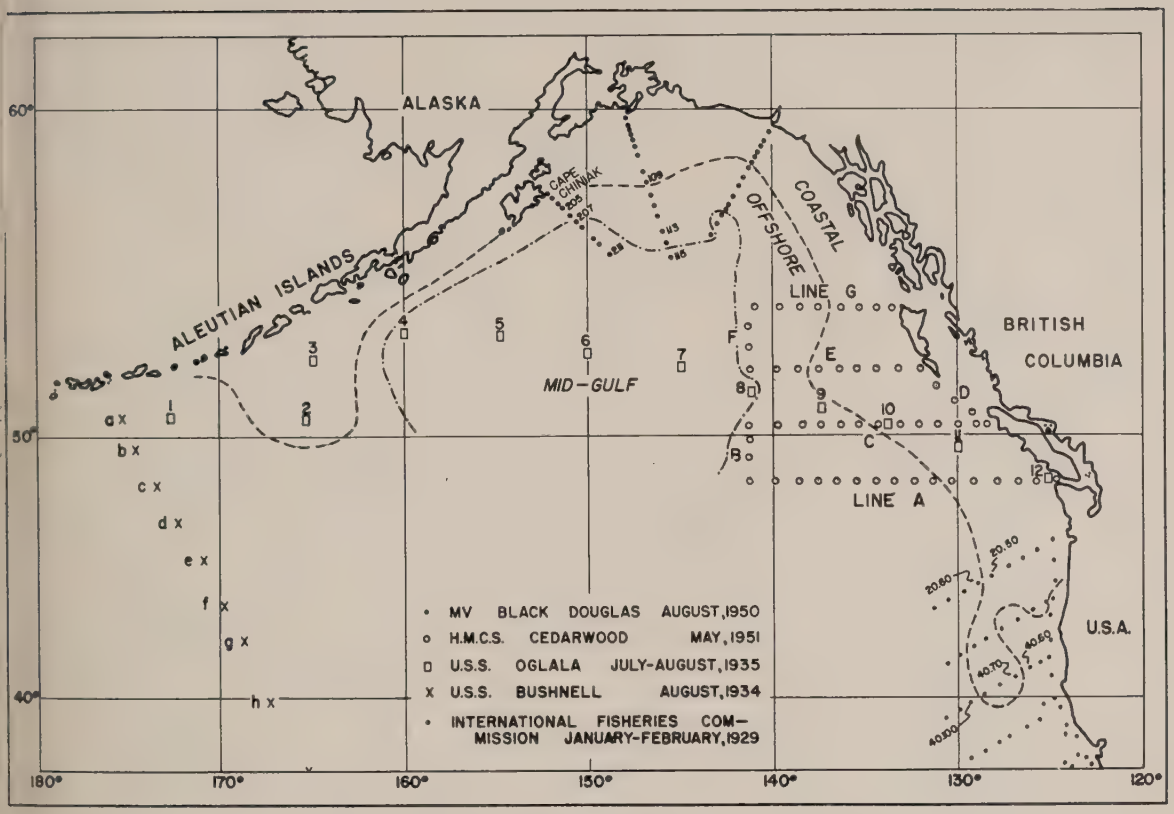


FIGURE 20. Water masses in the Gulf of Alaska (Doe, 1955).

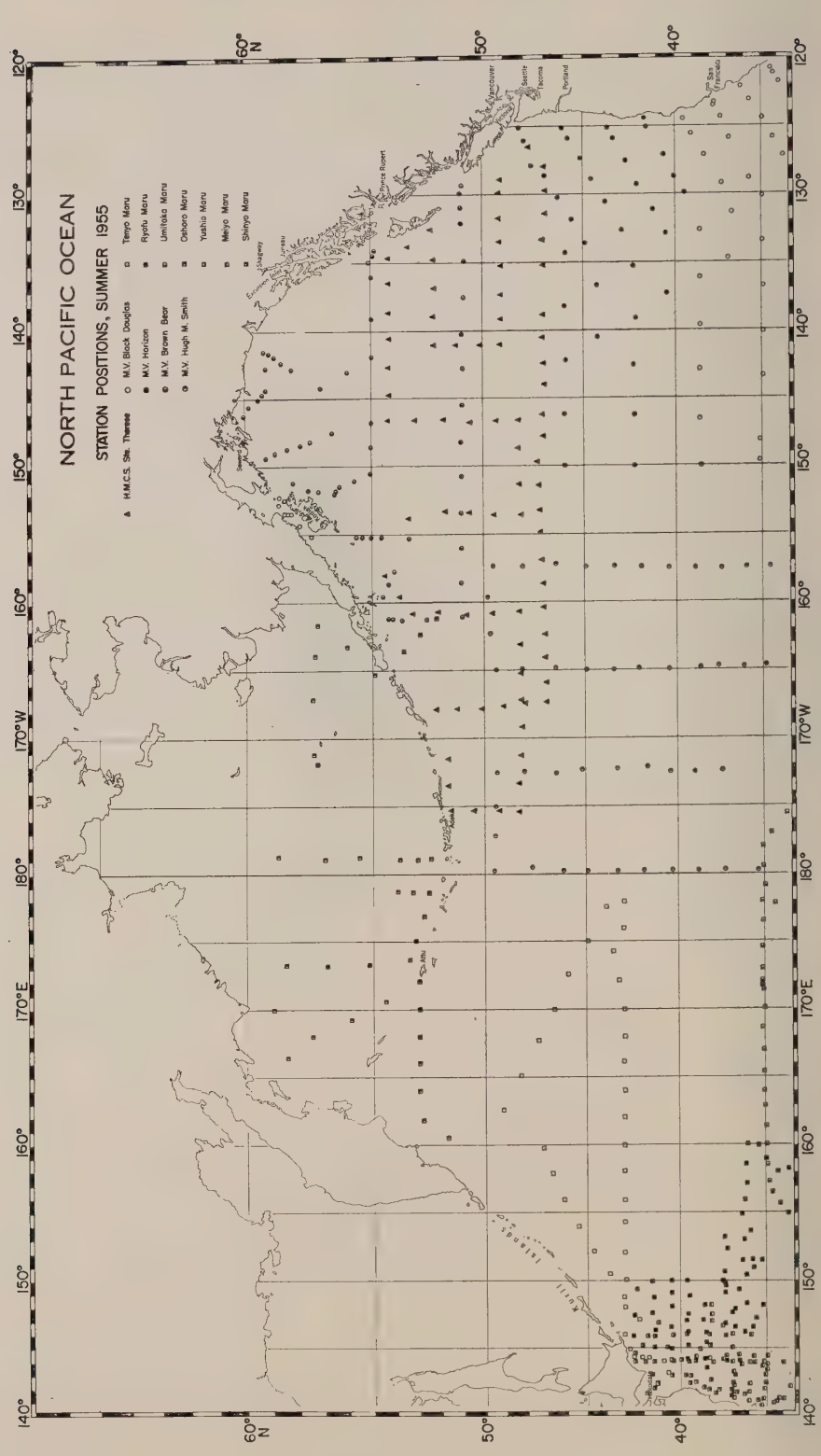


FIGURE 21. Station positions, summer 1955.

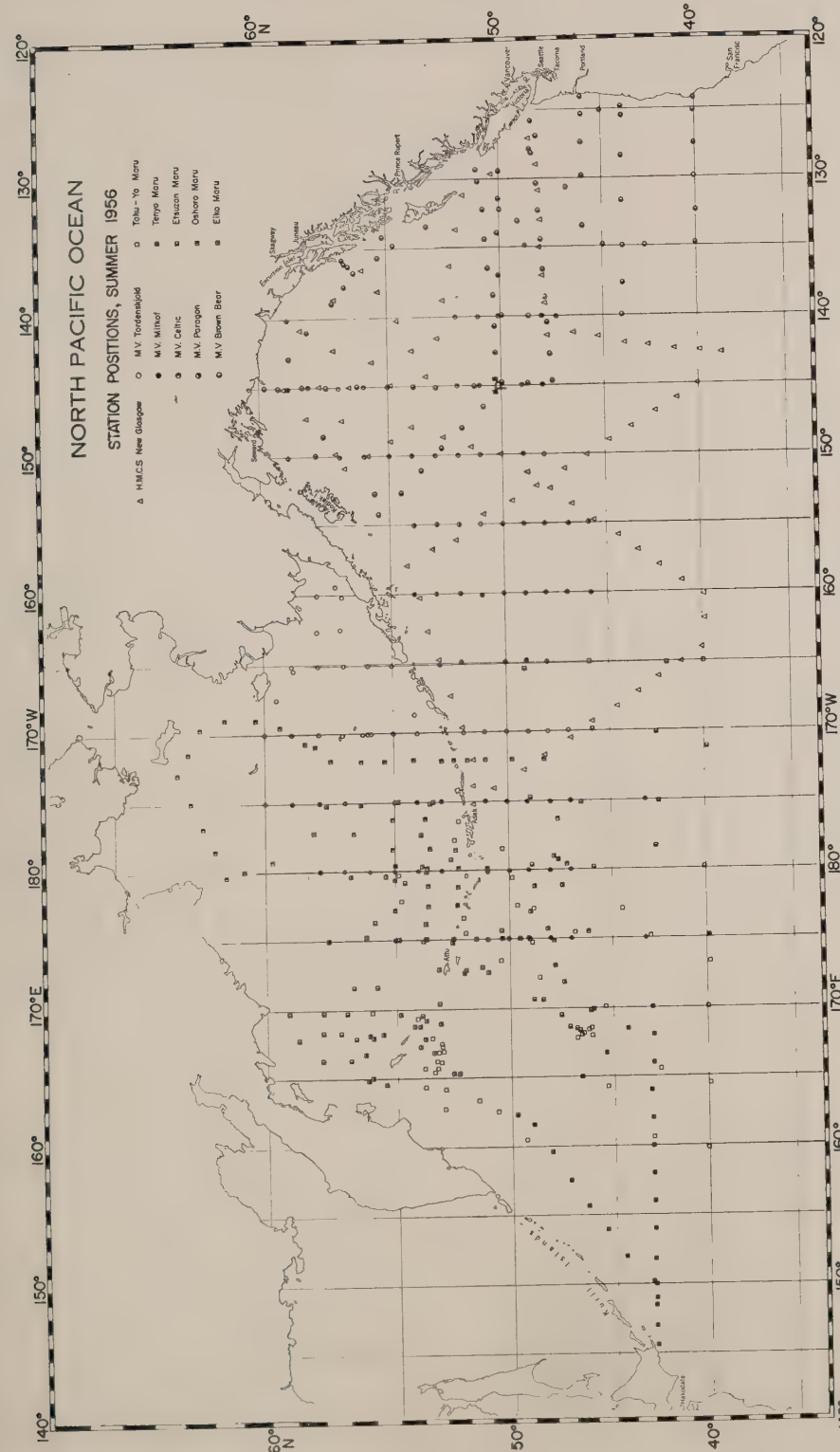


FIGURE 22. Station positions, summer 1956.

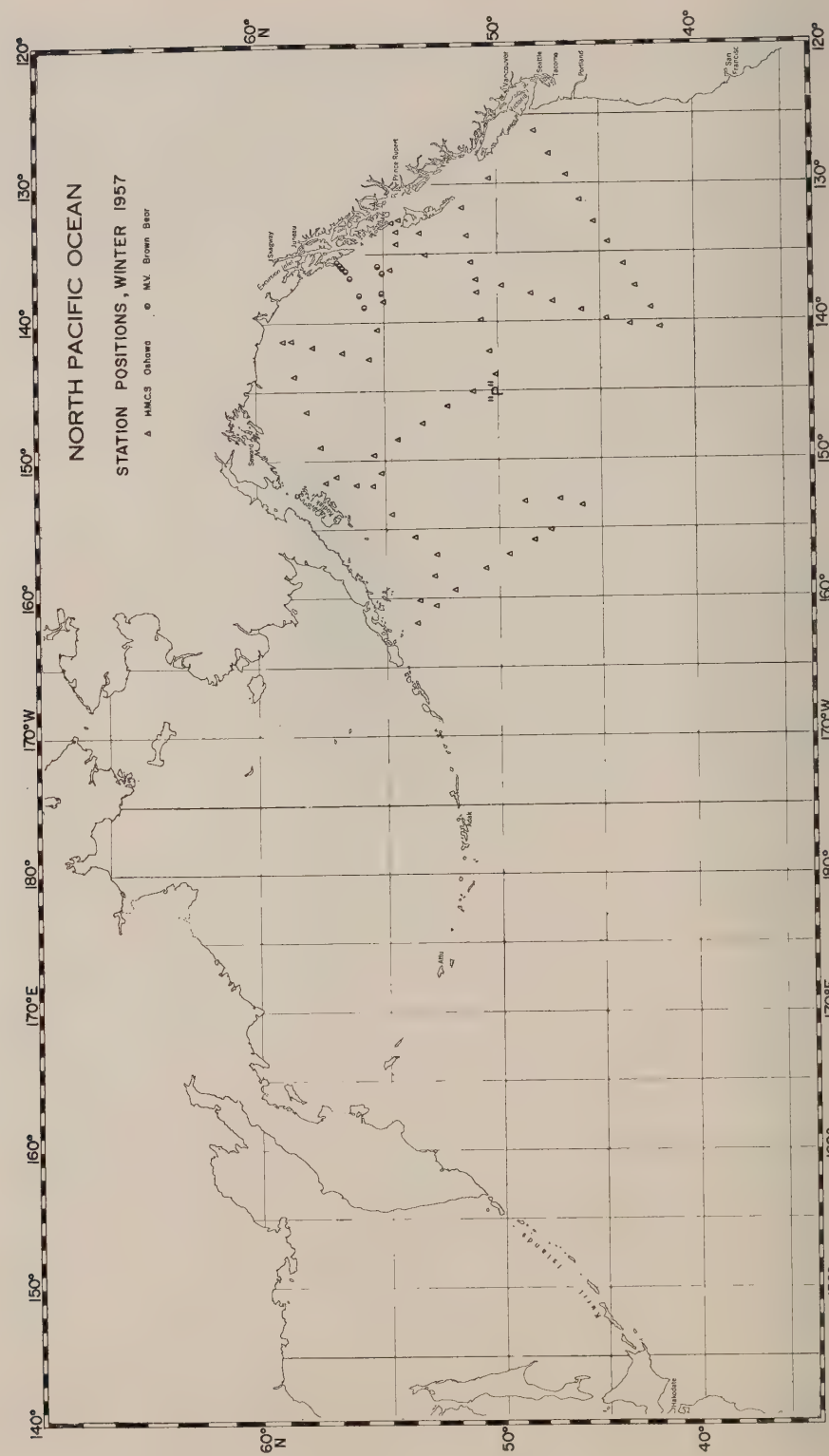


FIGURE 23. Station positions, winter 1957.

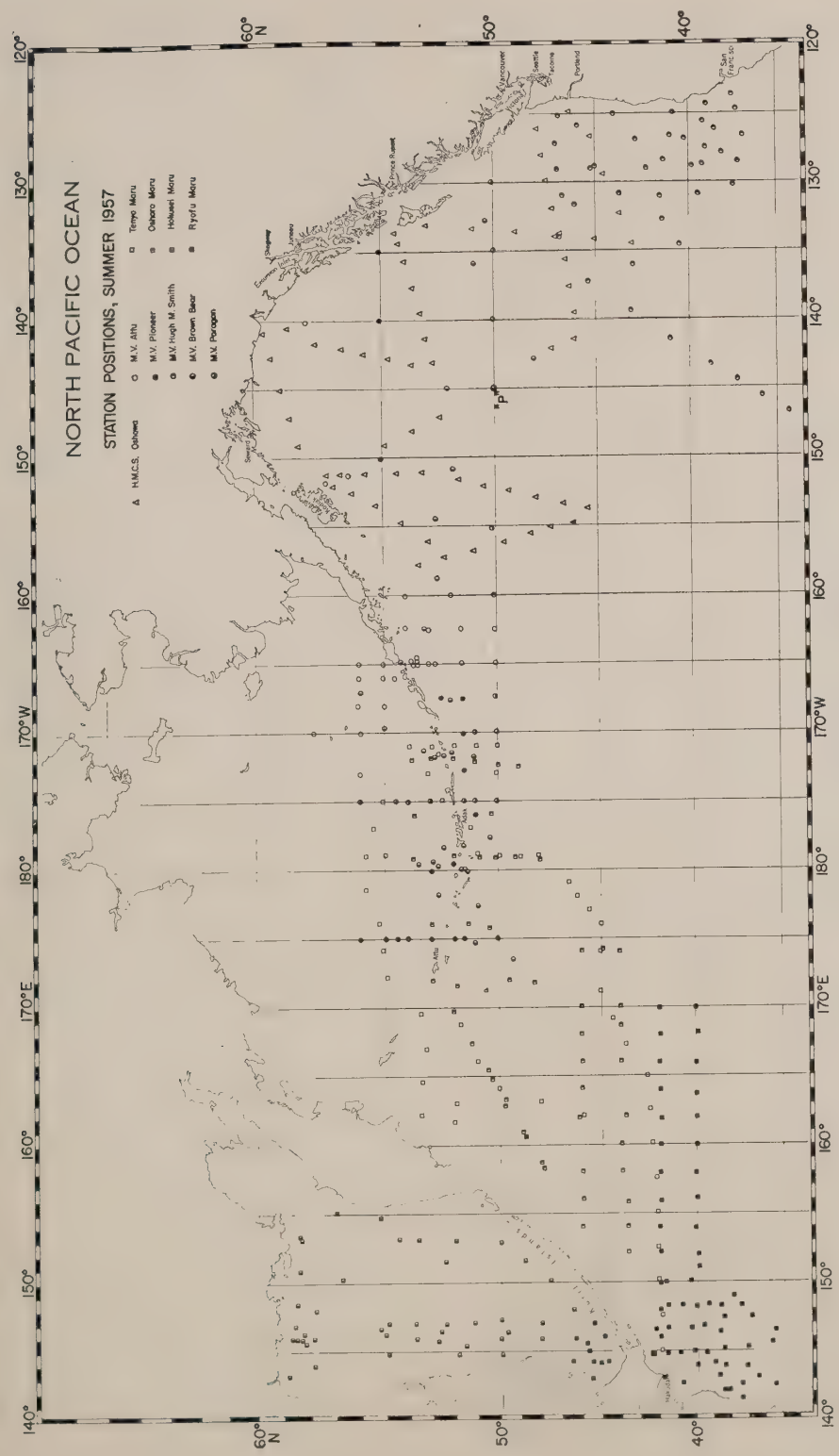


FIGURE 24. Station positions, summer 1957.

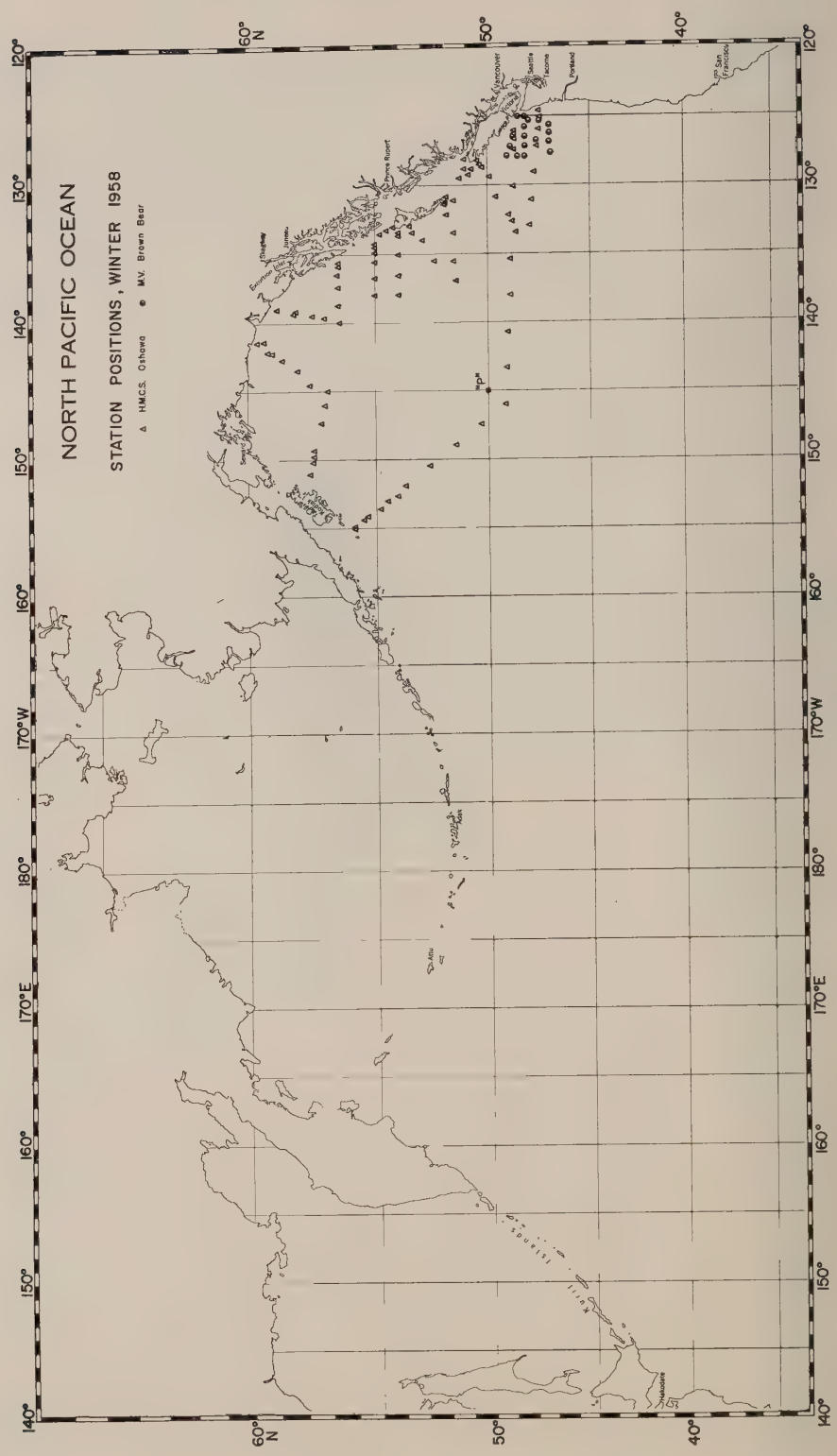


FIGURE 25. Station positions, winter 1958.

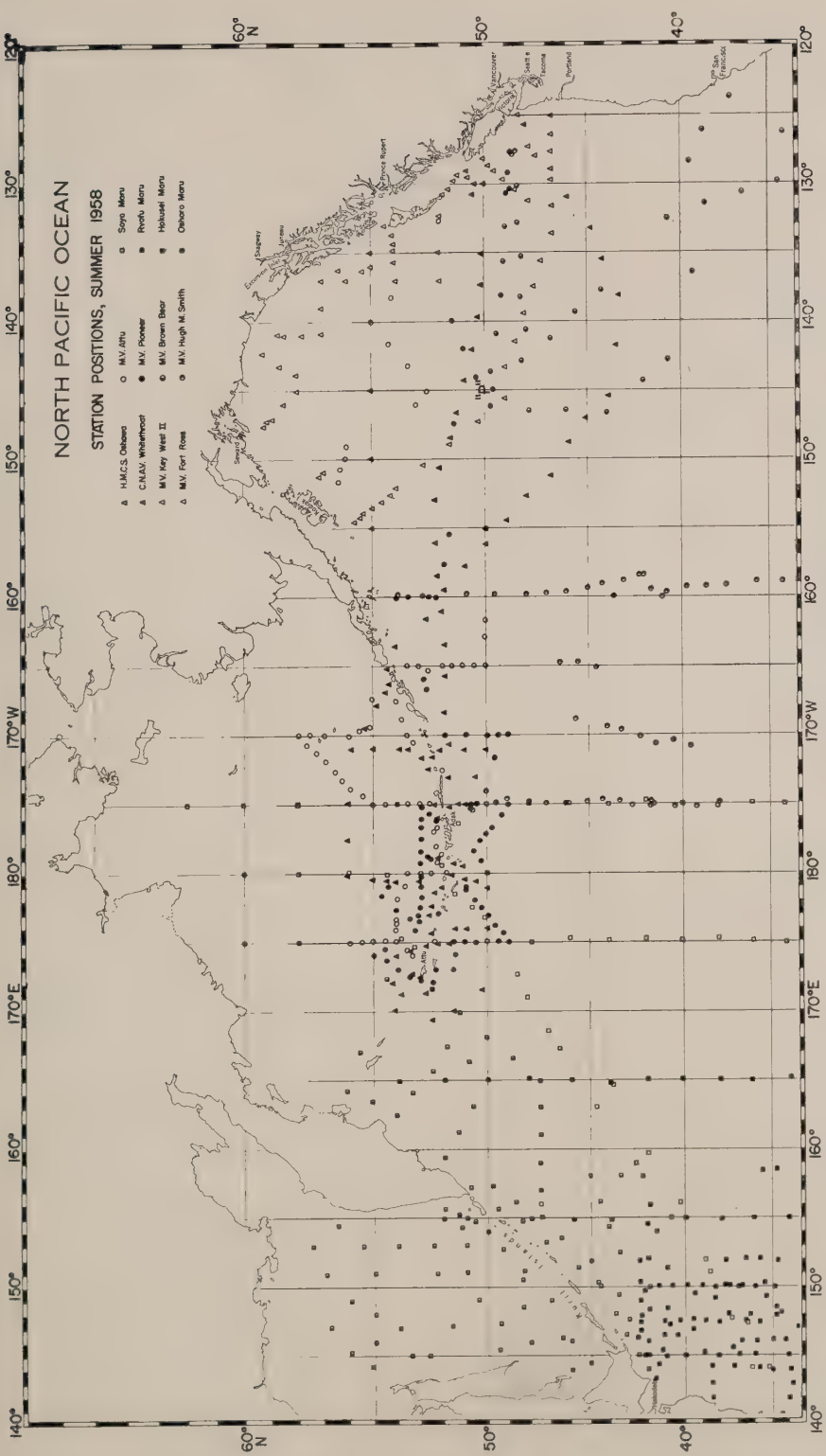


FIGURE 26. Station positions, summer 1958.

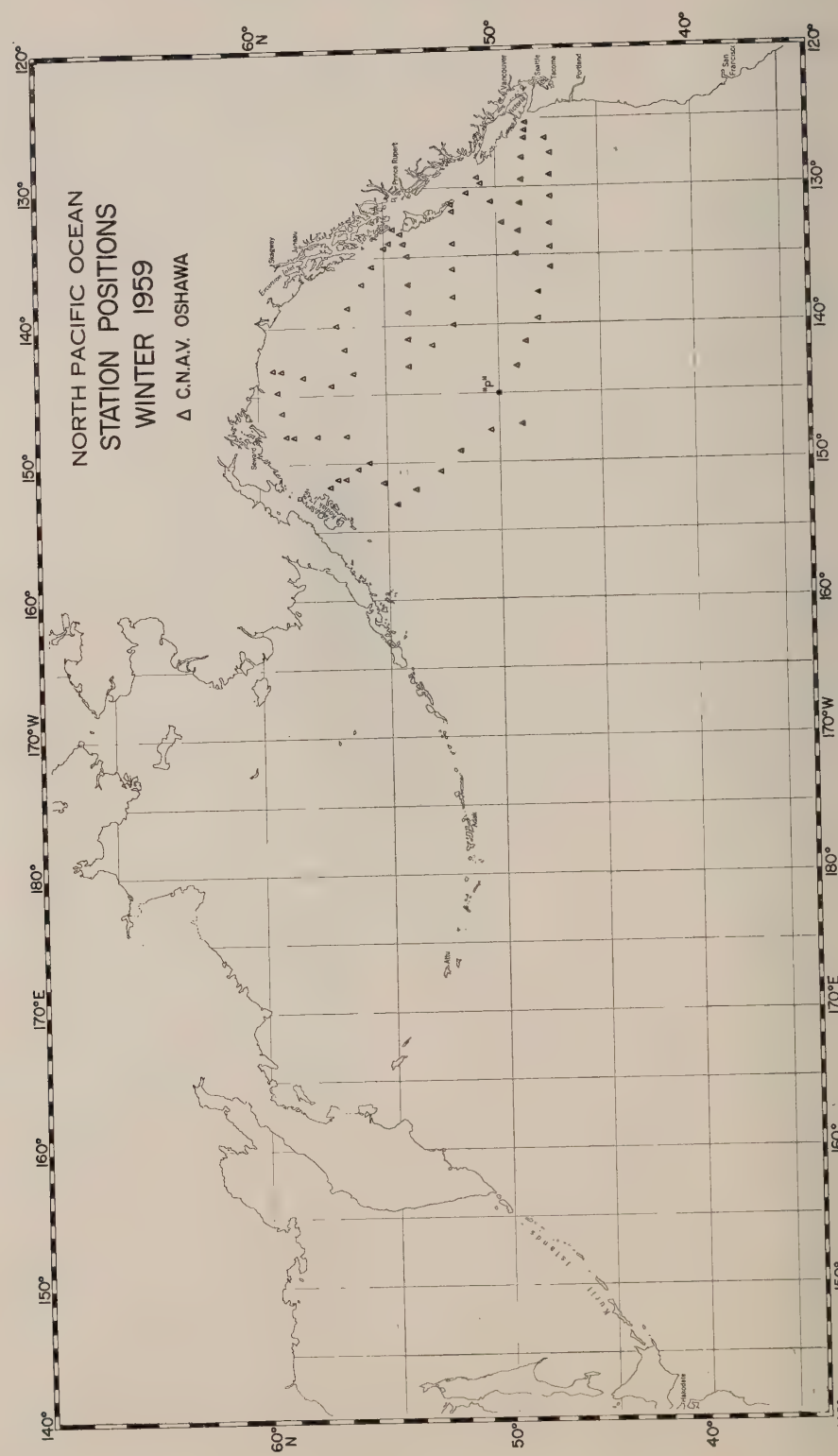


FIGURE 27. Station positions, winter 1959.

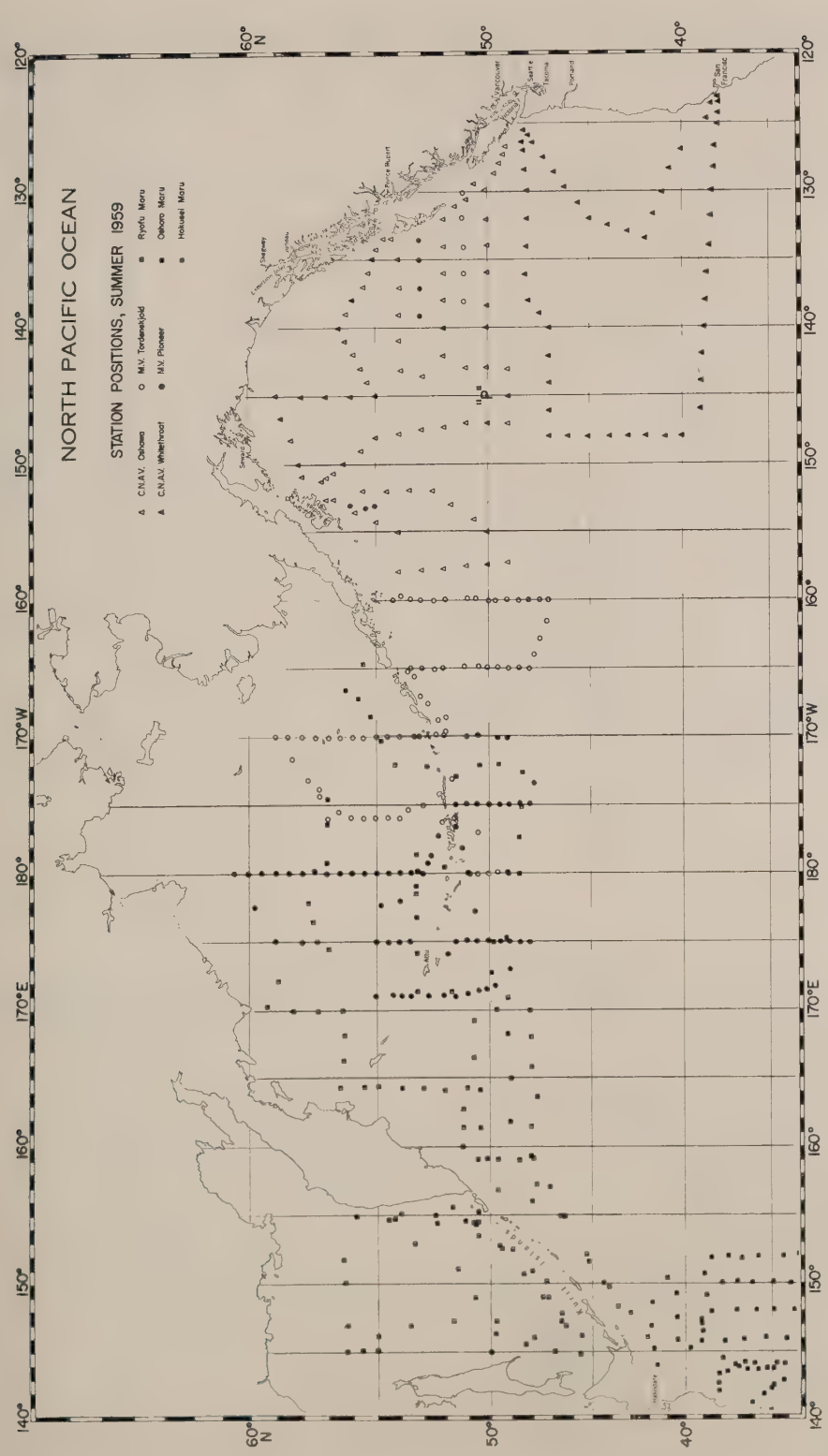


FIGURE 28. Station positions, summer 1959.

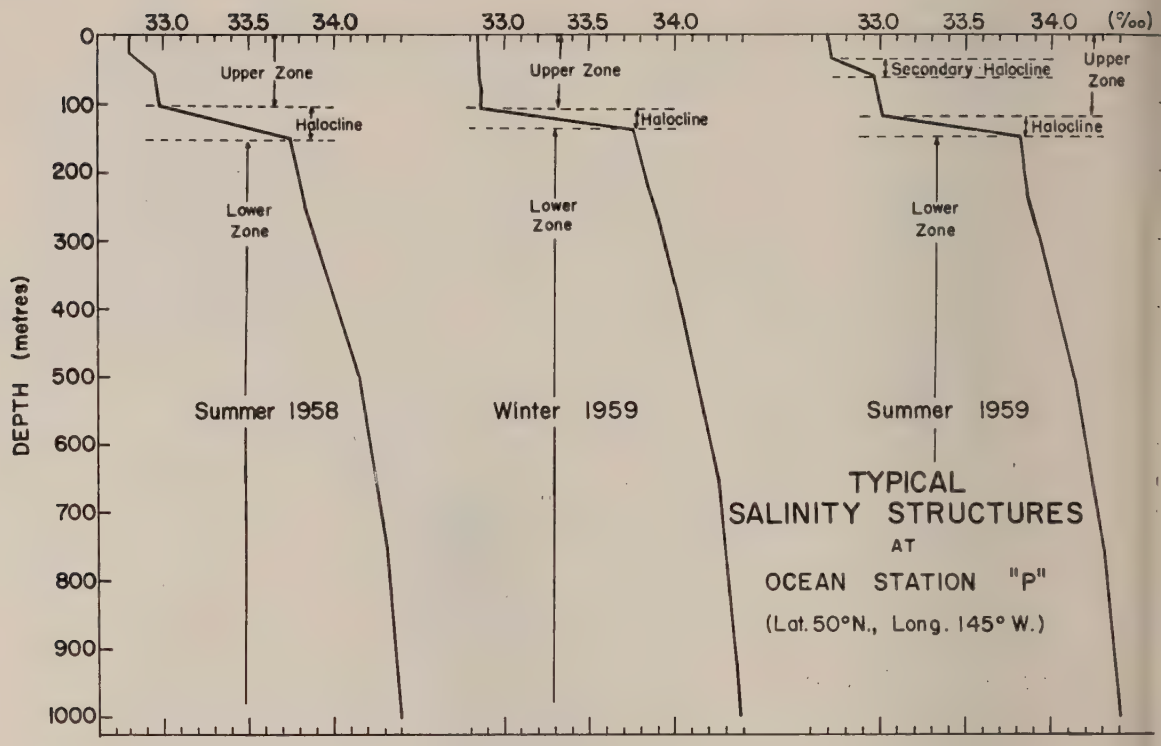


FIGURE 29. Typical salinity structures at Ocean Station "P".

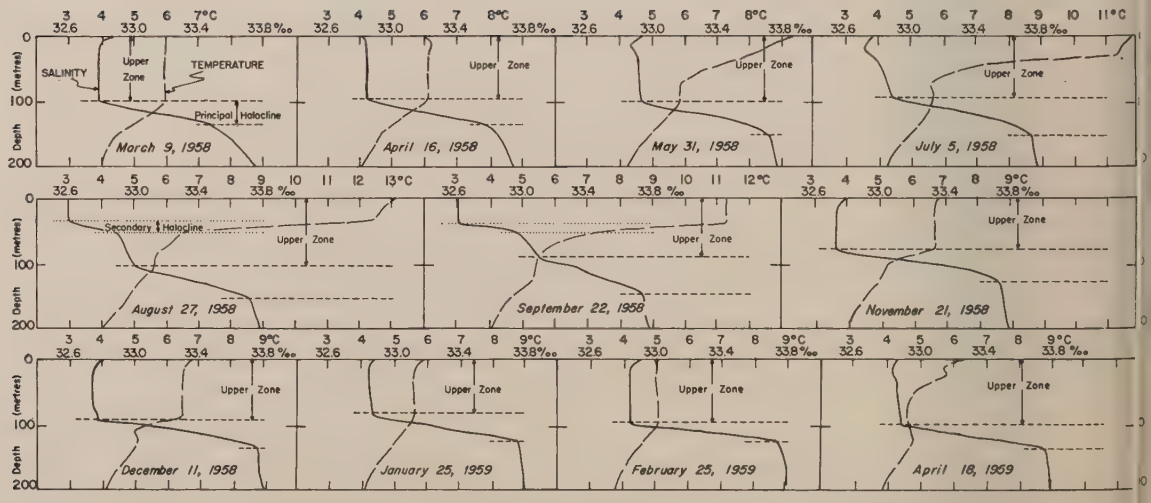


FIGURE 30. Salinity and temperature structures at Ocean Station "P", March 1958 to April 1959.

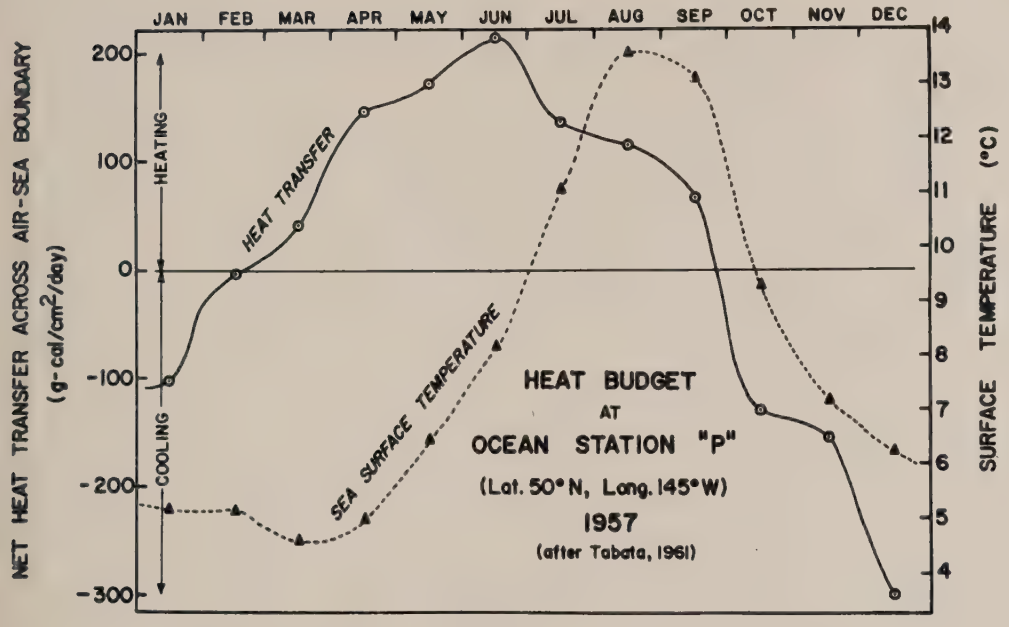


FIGURE 31. Heat budget at Ocean Station "P", 1957 (after Tabata, 1961).

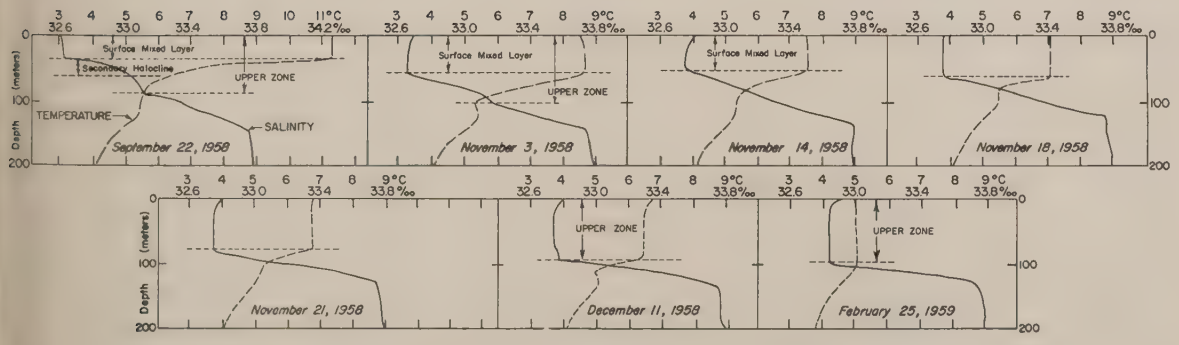
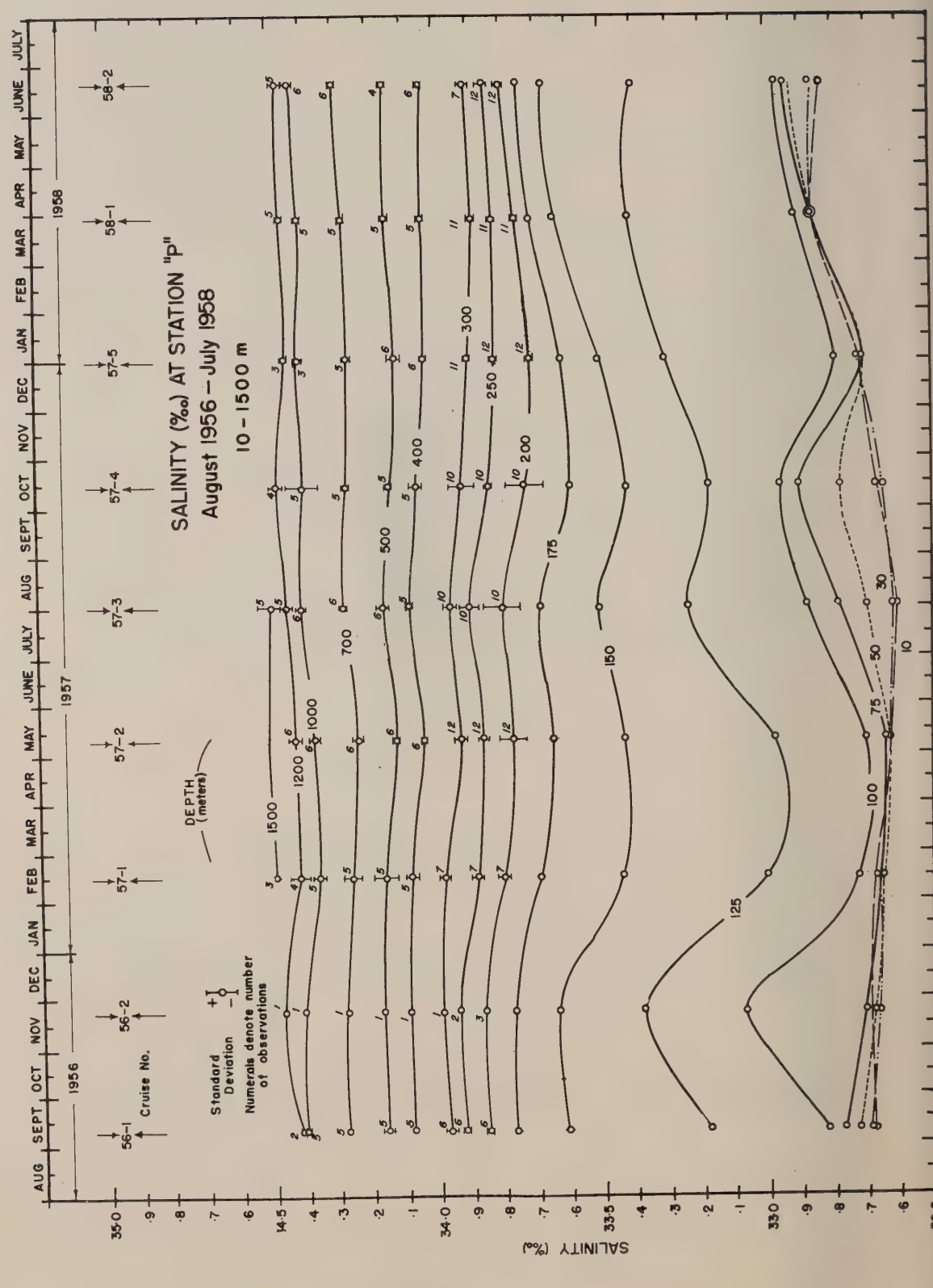


FIGURE 32. Salinity and temperature structures at Ocean Station "P", September 1958 to February 1959.


SALINITY (‰) AT STATION "P"
August 1956 – July 1958
10 – 1500 m
Cruise No.
Standard Deviation +1 −1
Numerals denote number of observations
DEPTH (meters)
SALINITY (‰)
AUG SEPT OCT NOV DEC JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC JAN FEB MAR APR MAY JUNE JULY
1956
1957
1958
56-1
56-2
57-1
57-2
57-3
57-4
57-5
58-1
58-2
1500
1200
1000
700
500
400
300
250
200
175
150
125
100
75
50
30
10

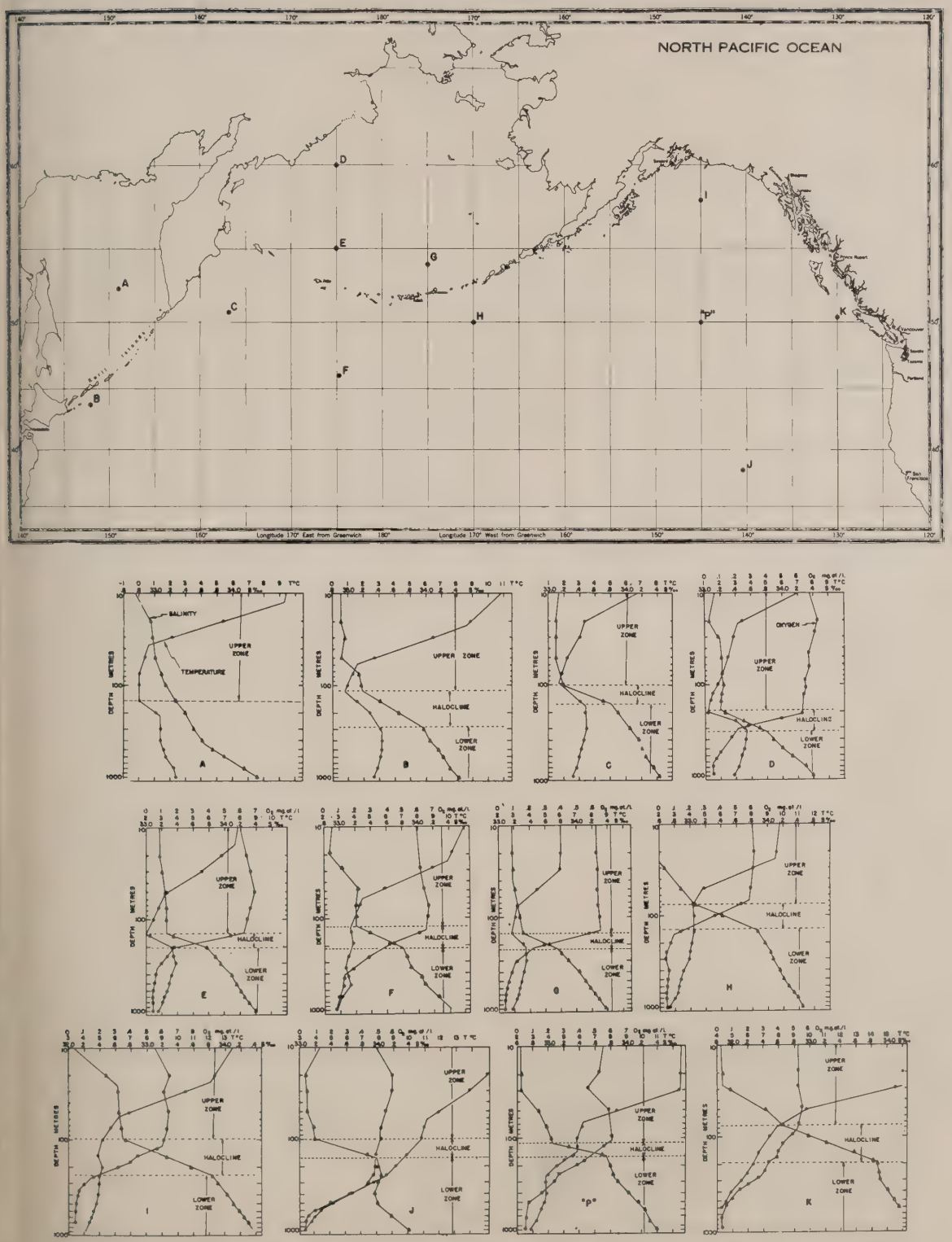


FIGURE 34. Typical salinity, temperature and dissolved oxygen structures in the Subarctic Region, summer 1958.

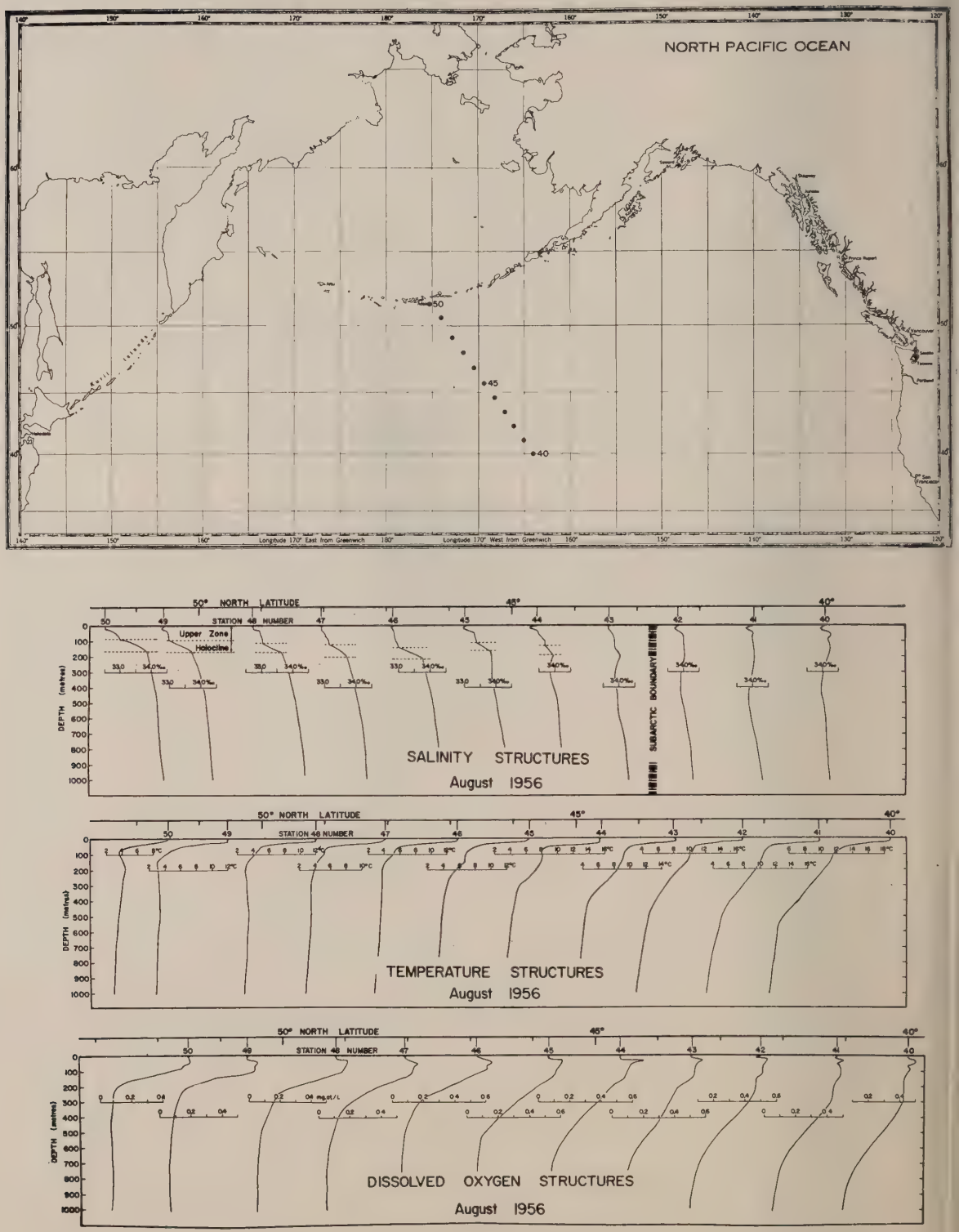


FIGURE 35. Sequence of salinity, temperature, and dissolved oxygen structures from lat. 50°N. to 40°N., summer 1956.

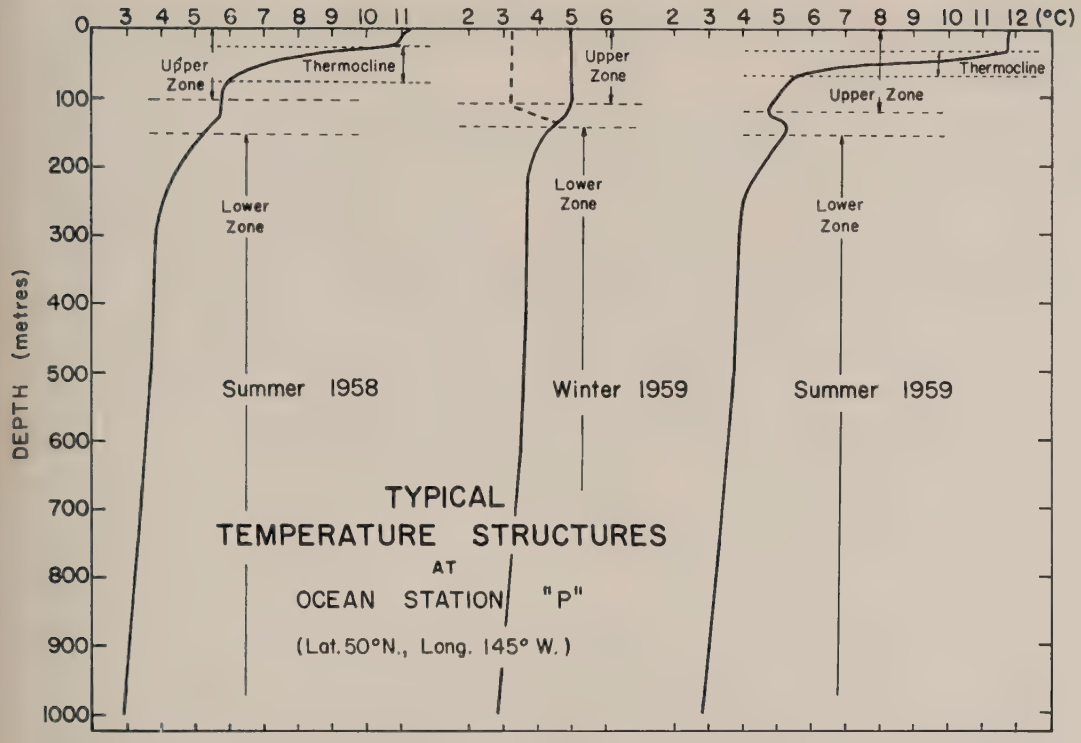


FIGURE 36. Typical temperature structures at Ocean Station "P" (dotted line at top winter structure indicates possible deviation with extreme cooling).

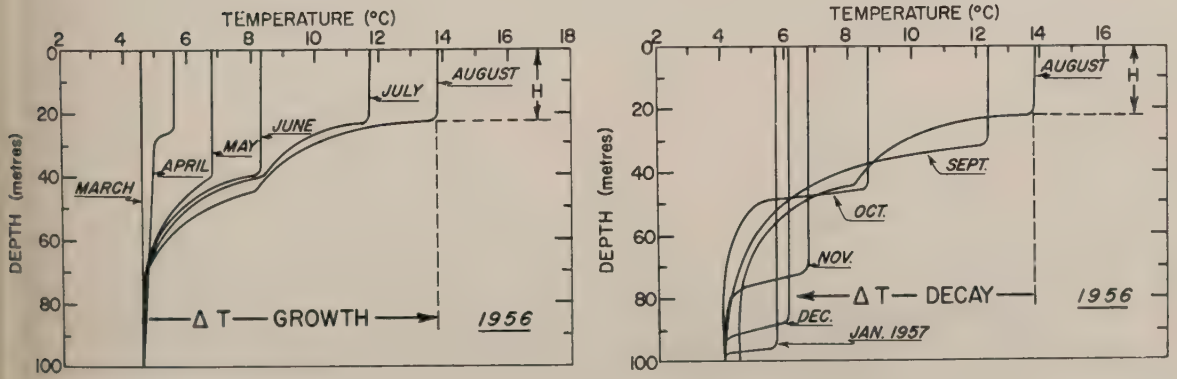


FIGURE 37. Growth and decay of the thermocline at Ocean Station "P".

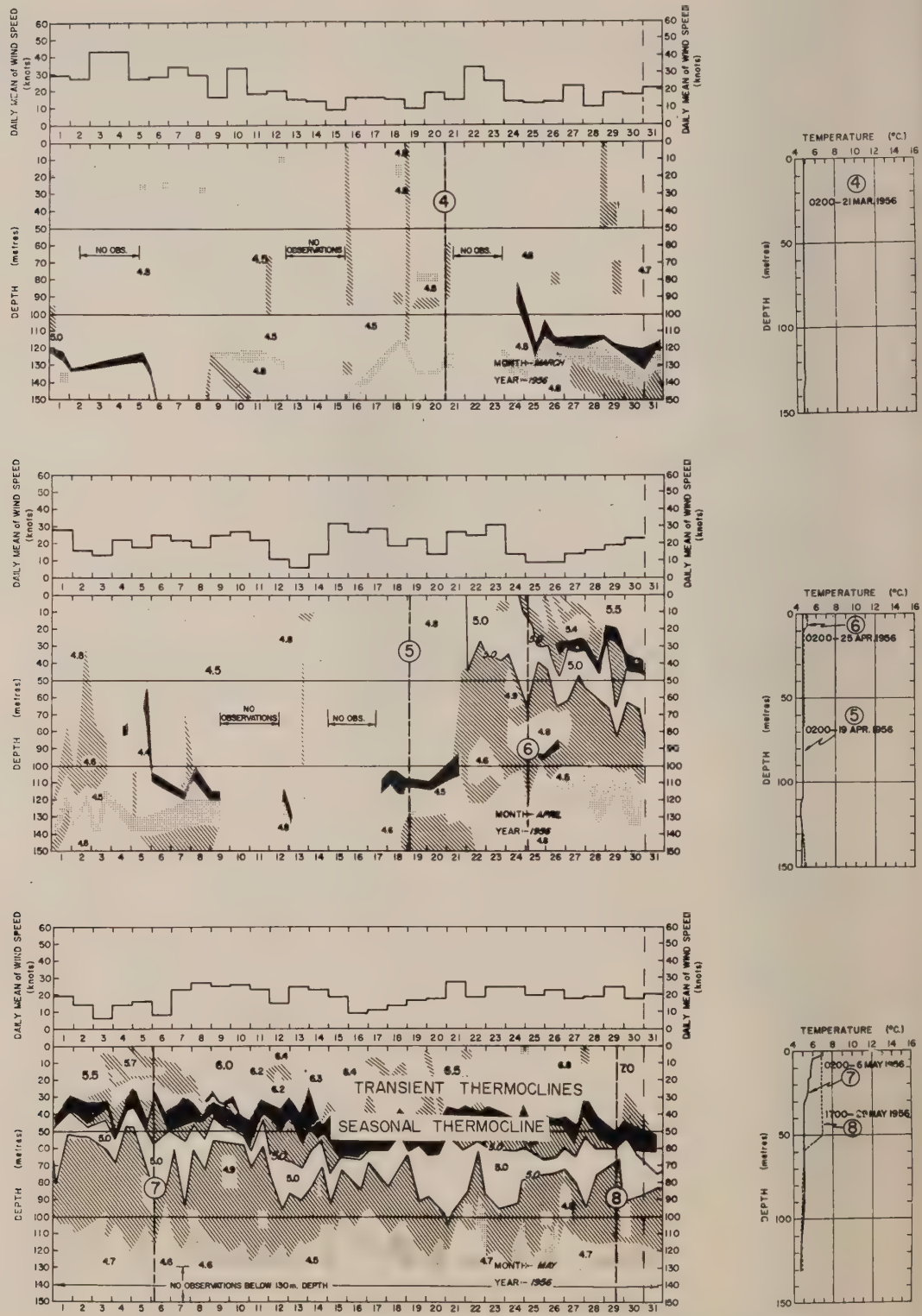


FIGURE 38a. Features of the thermocline at Ocean Station "P", March, April, May, 1956.

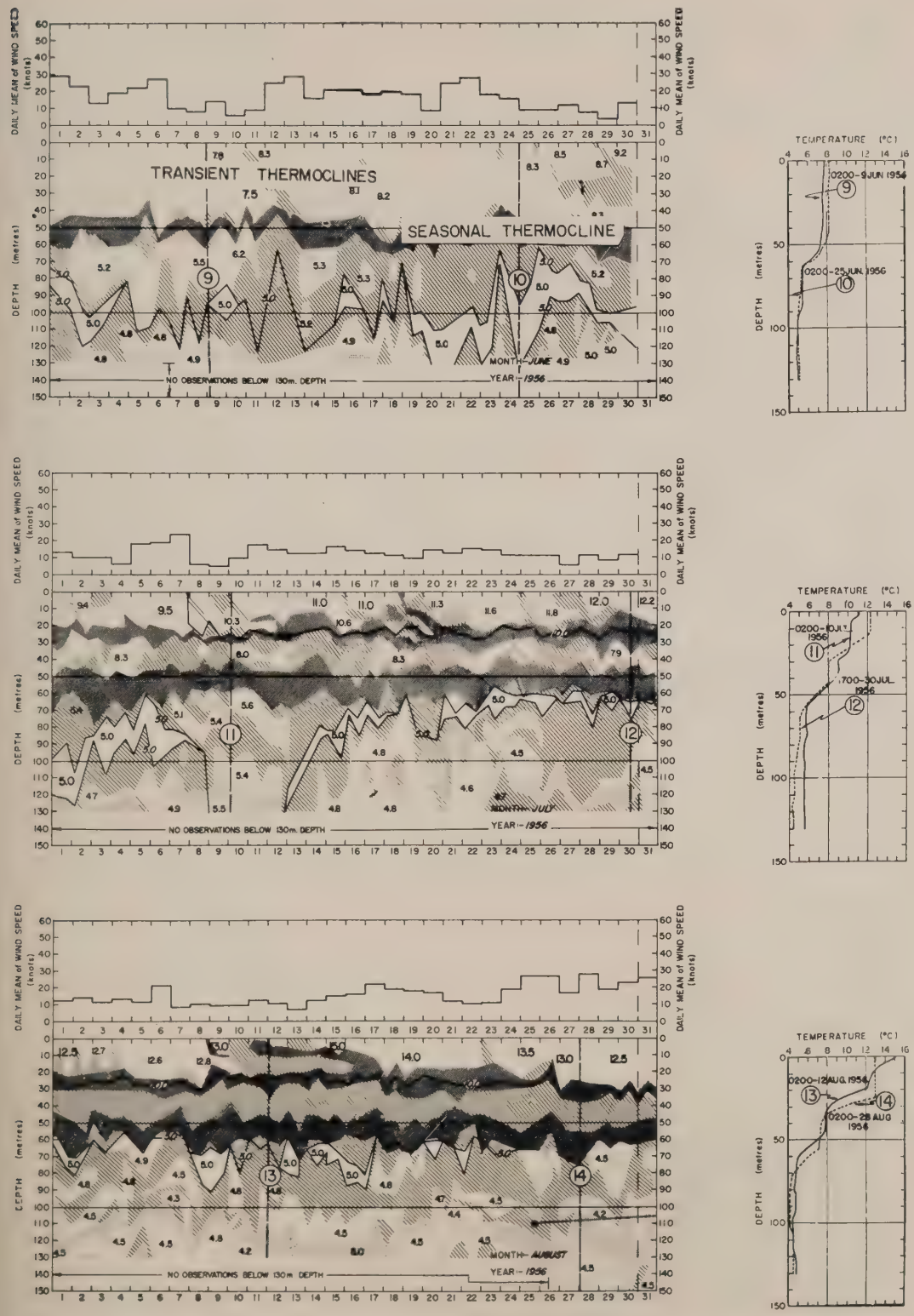


FIGURE 38b. Features of the thermocline at Ocean Station "P", June, July, August, 1956.

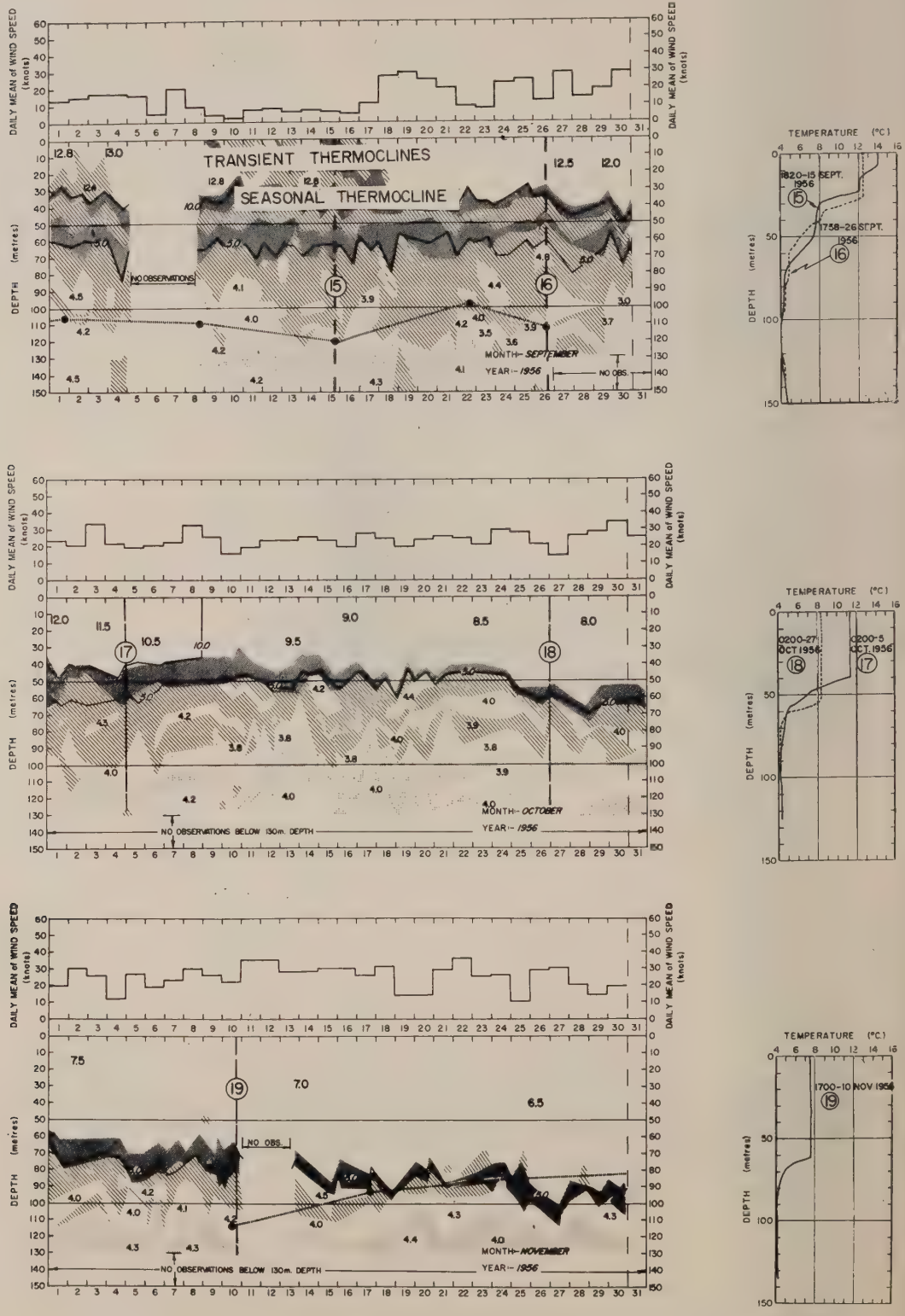


FIGURE 38c. Features of the thermocline at Ocean Station "P", September, October, November, 1956.

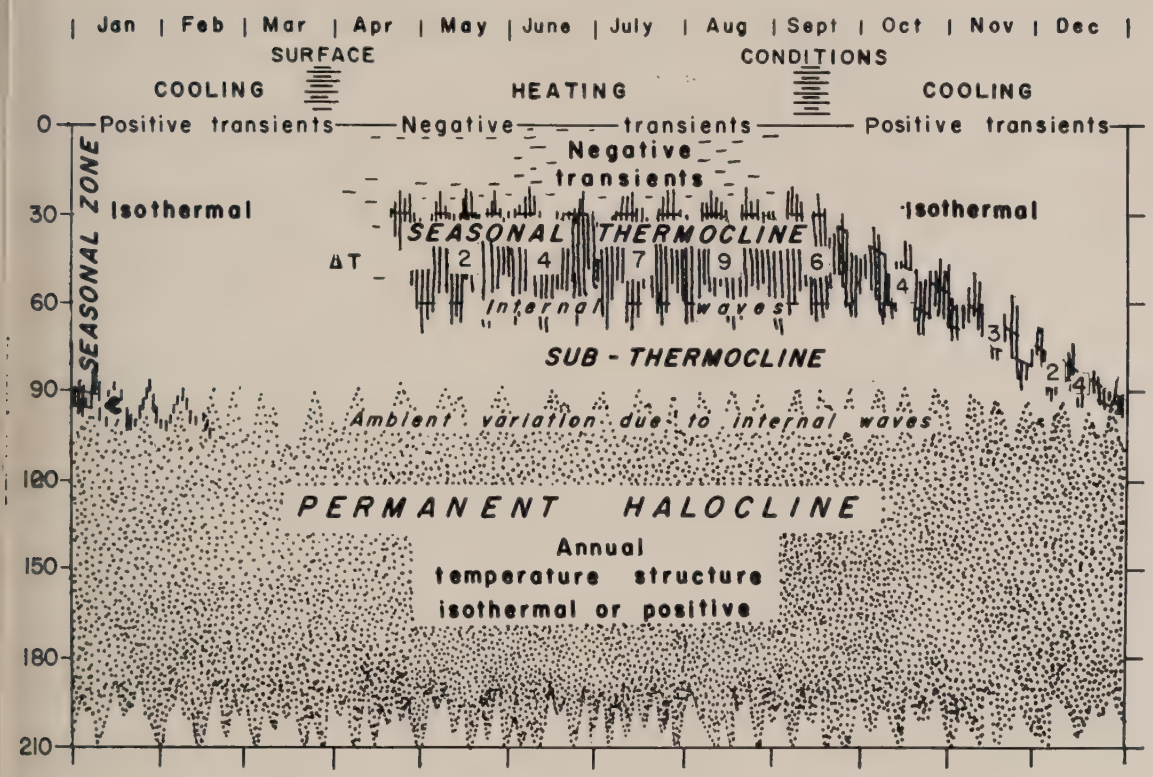
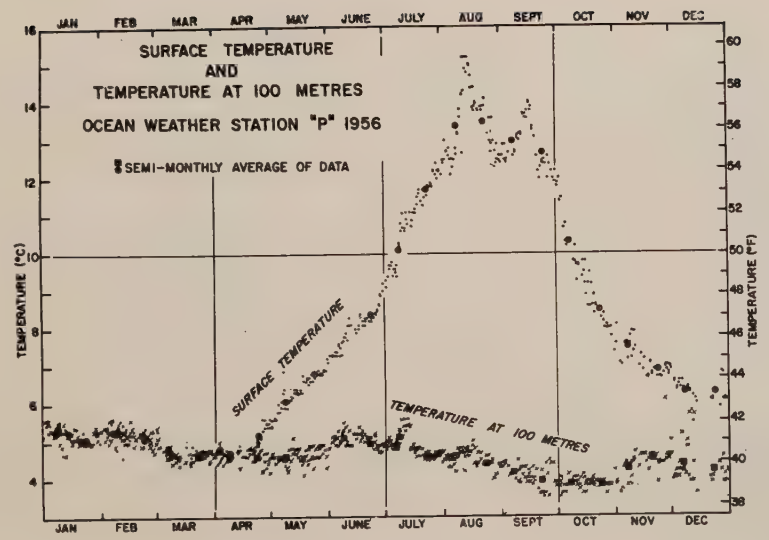
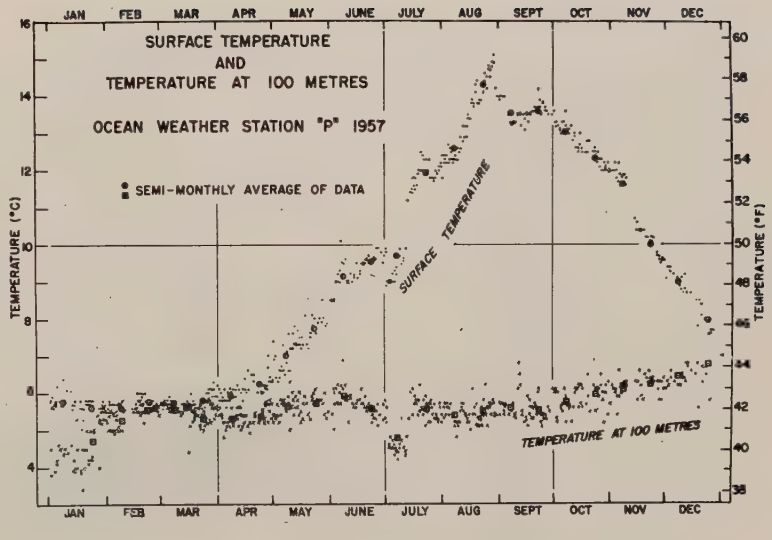
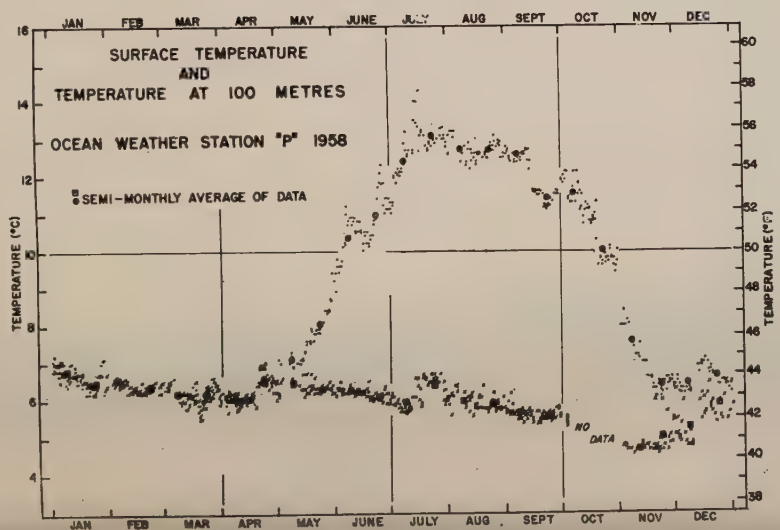
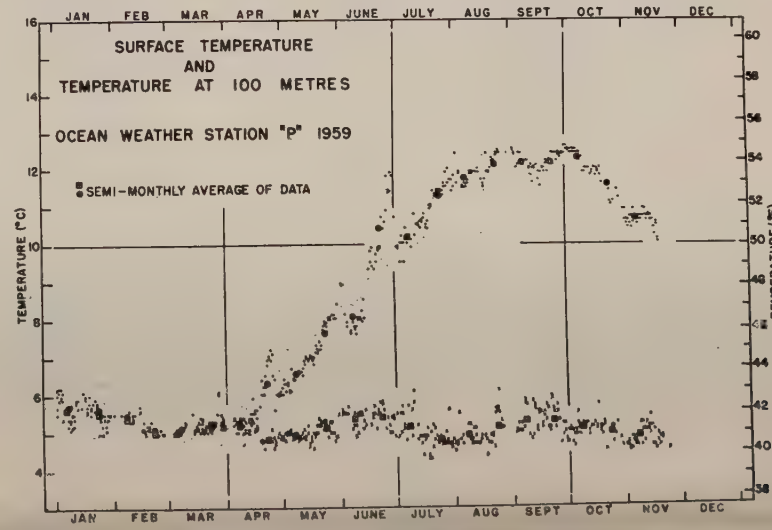


FIGURE 39. Schematic diagram of significant features of structure.


SURFACE TEMPERATURE
AND
TEMPERATURE AT 100 METRES
OCEAN WEATHER STATION "P" 1956
SEMI-MONTHLY AVERAGE OF DATA
SURFACE TEMPERATURE
TEMPERATURE AT 100 METRES
TEMPERATURE (°C)
TEMPERATURE (°F)
JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC


SURFACE TEMPERATURE
AND
TEMPERATURE AT 100 METRES
OCEAN WEATHER STATION "P" 1957
SEMI-MONTHLY AVERAGE OF DATA
SURFACE TEMPERATURE
TEMPERATURE AT 100 METRES
TEMPERATURE (°C)
TEMPERATURE (°F)
JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC


SURFACE TEMPERATURE
AND
TEMPERATURE AT 100 METRES
OCEAN WEATHER STATION "P" 1958
SEMI-MONTHLY AVERAGE OF DATA
NO DATA
TEMPERATURE (°C)
TEMPERATURE (°F)
JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC


SURFACE TEMPERATURE
AND
TEMPERATURE AT 100 METRES
OCEAN WEATHER STATION "P" 1959
SEMI-MONTHLY AVERAGE OF DATA
TEMPERATURE (°C)
TEMPERATURE (°F)
JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC

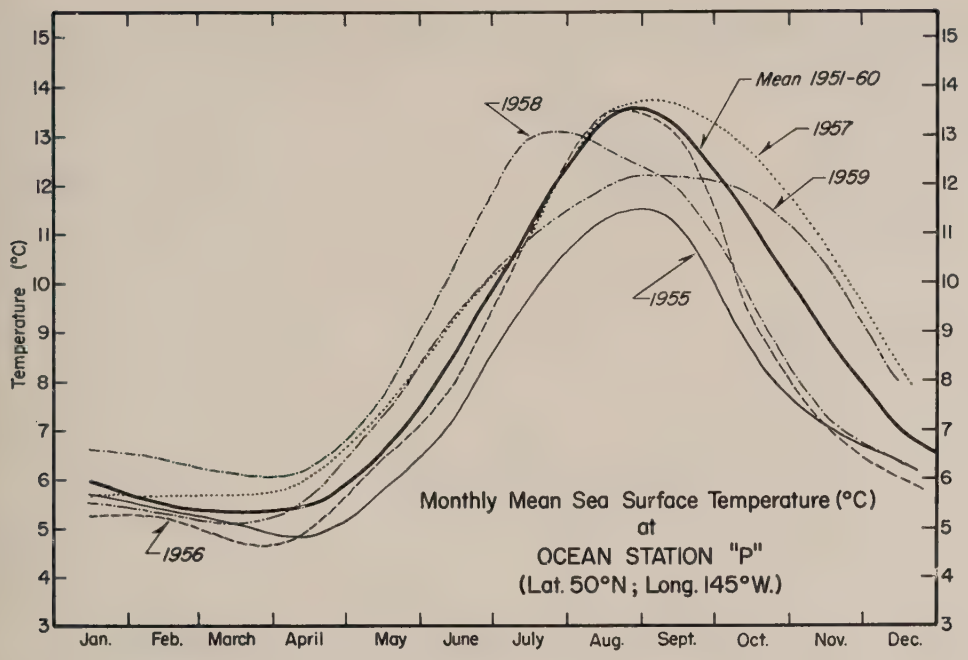


FIGURE 41. Monthly mean sea surface temperature at Ocean Station "P", 1955 through 1959.

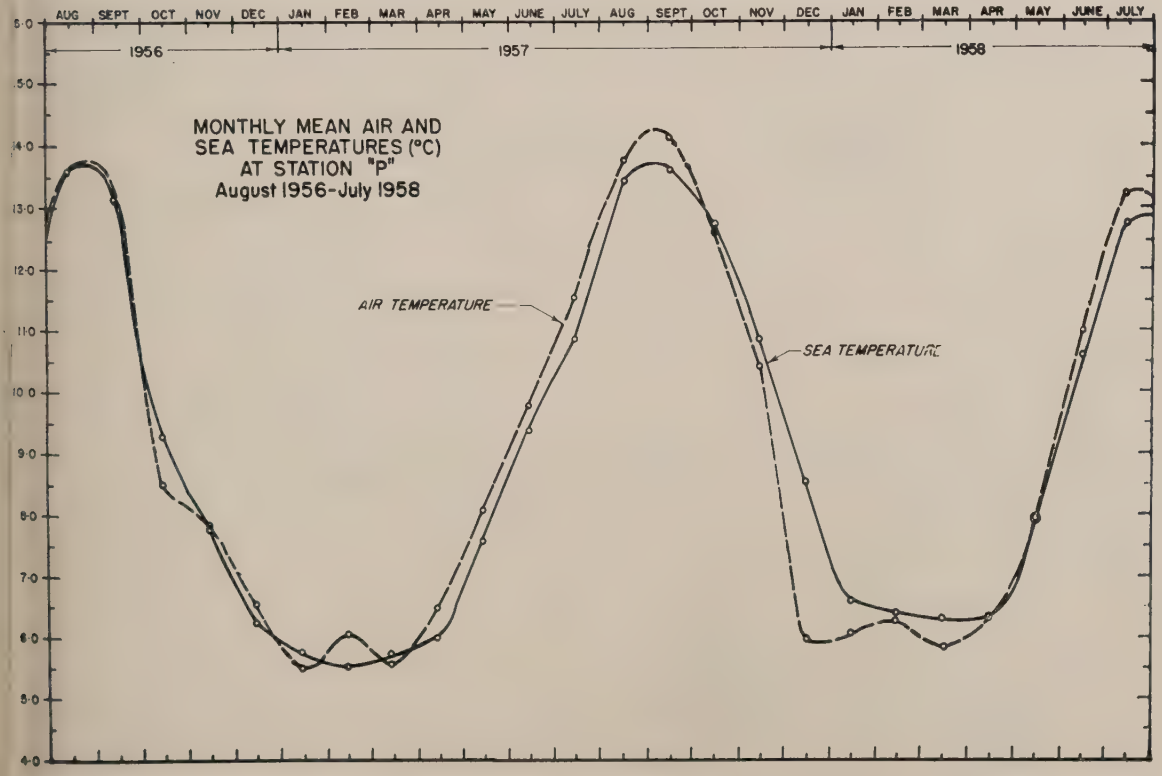

AUG SEPT OCT NOV DEC JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC JAN FEB MAR APR MAY JUNE JULY
1956
1957
1958
MONTHLY MEAN AIR AND
SEA TEMPERATURES (°C)
AT STATION "P"
August 1956-July 1958
AIR TEMPERATURE
SEA TEMPERATURE

FIGURE 42. Monthly mean air and sea temperatures at Ocean Station "P", August 1956 to July 1958.

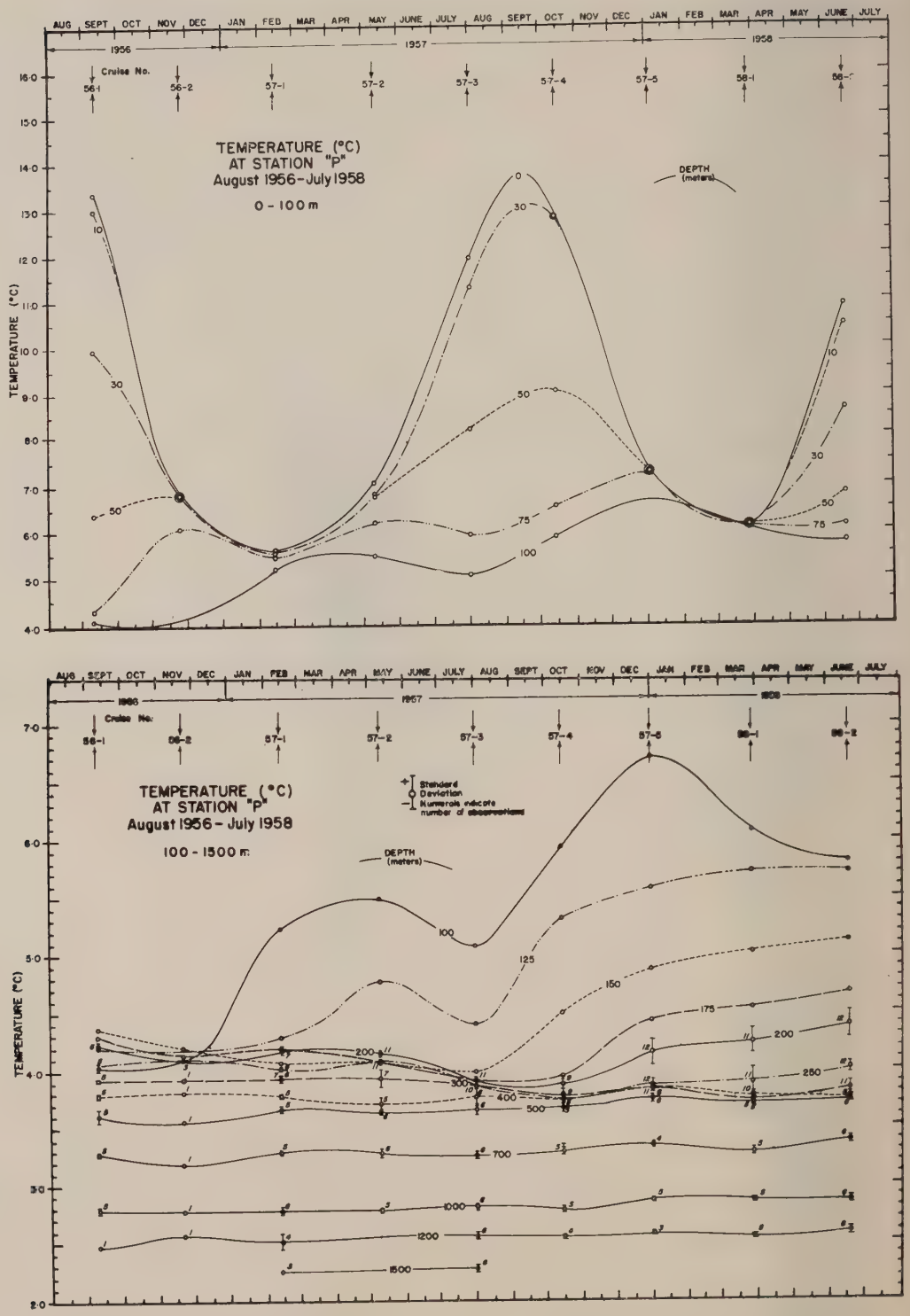


FIGURE 43. Values of temperature at selected depths at Ocean Station "P", August 1956 to July 1958 (Tabata, 1961) (std. dev. not shown at 10 to 175 m.).

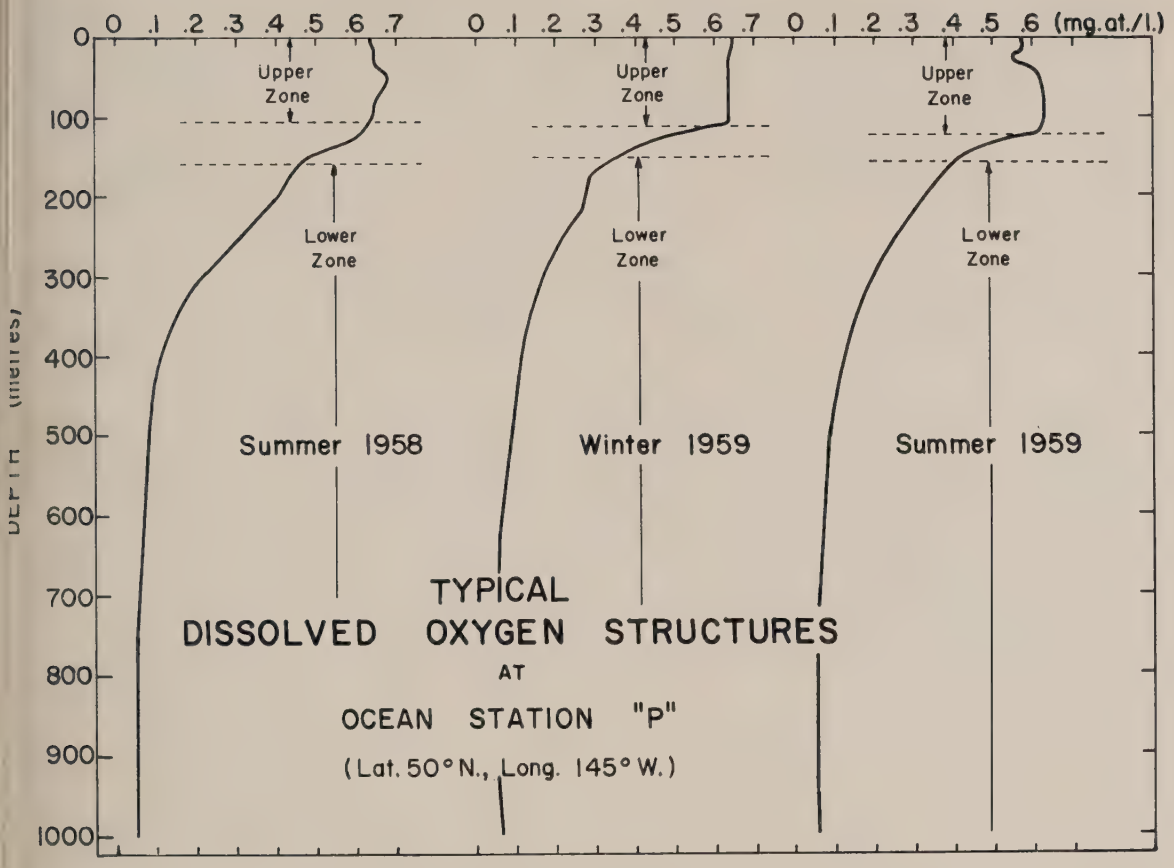


FIGURE 44. Typical dissolved oxygen structures at Ocean Station "P".

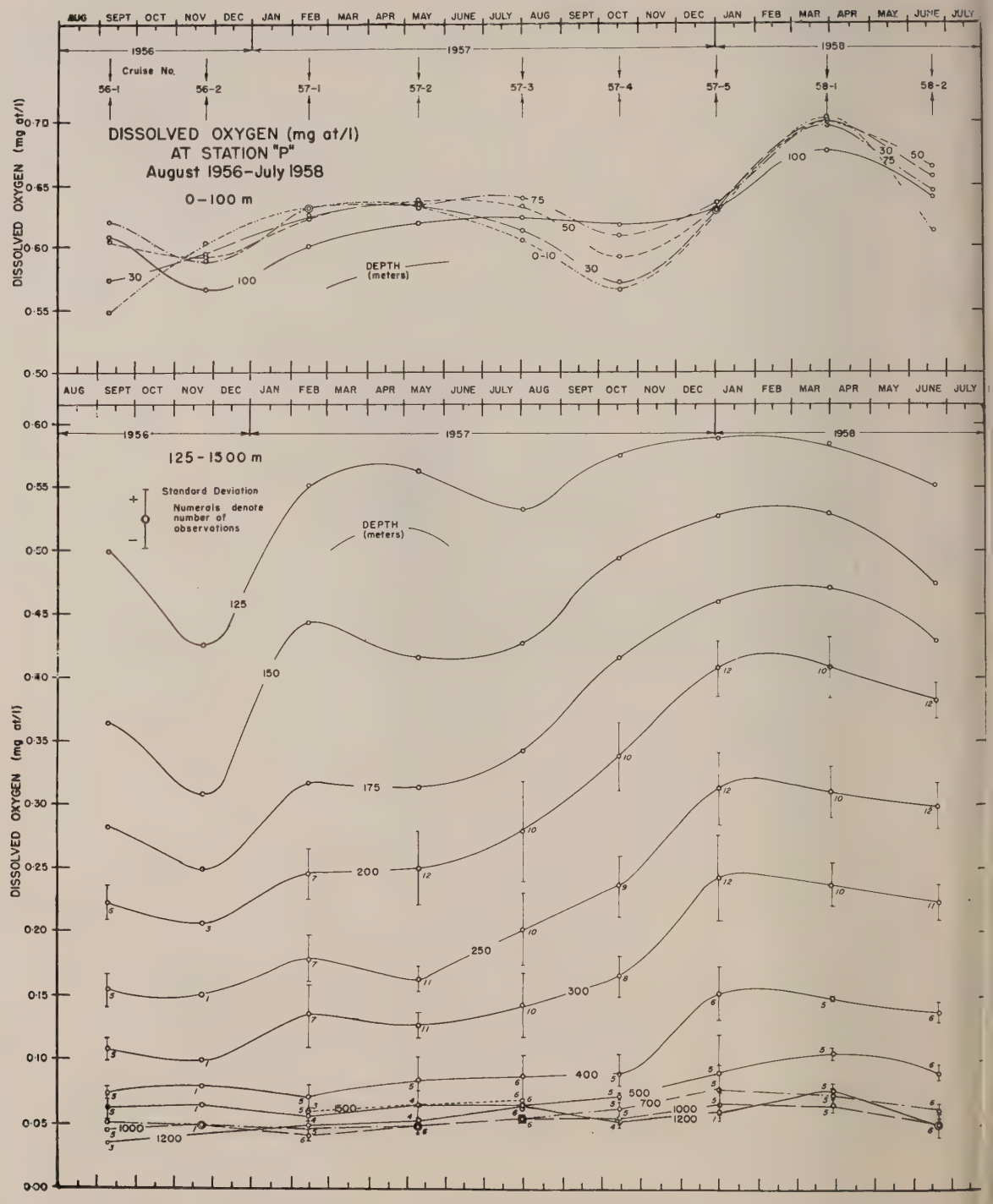


FIGURE 45. Values of dissolved oxygen at selected depths at Ocean Station "P", August 1956 to July 1958 (Tabata, 1961) (std. dev. not shown at 10 to 175 m.).

FIGURE 46. Locations of vertical sections, summer 1955.

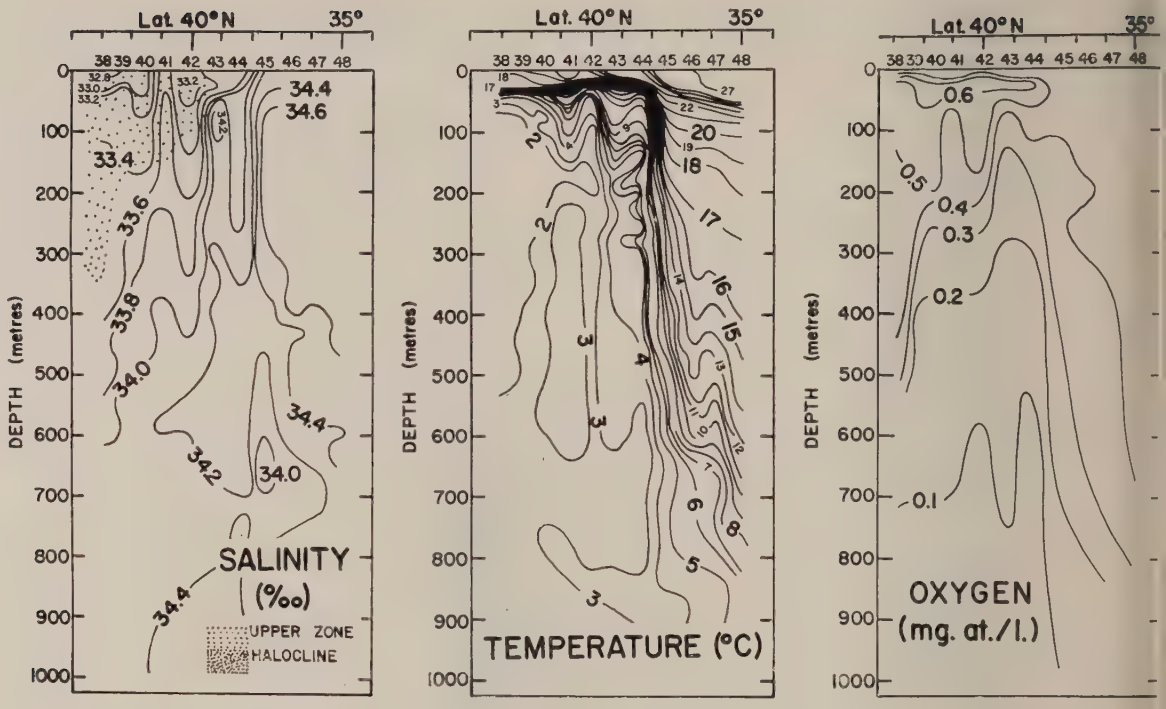


FIGURE 47. Vertical sections of salinity, temperature and dissolved oxygen along approx. long. 145°E., summer 1955.

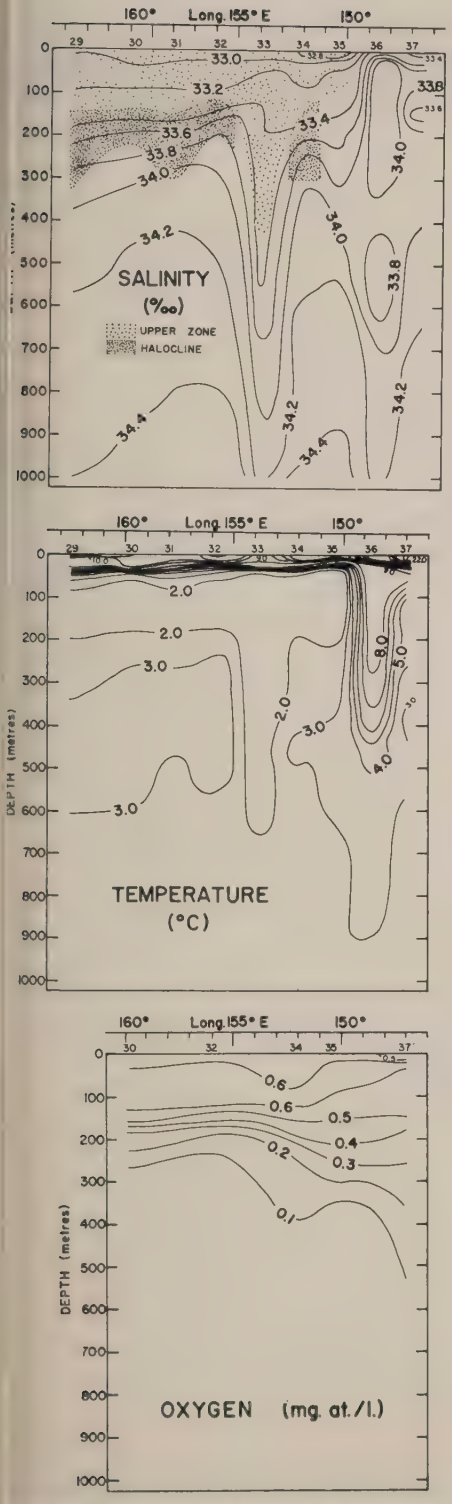


FIGURE 48. Vertical sections of salinity, temperature and dissolved oxygen along Kuril Islands, summer 1955.

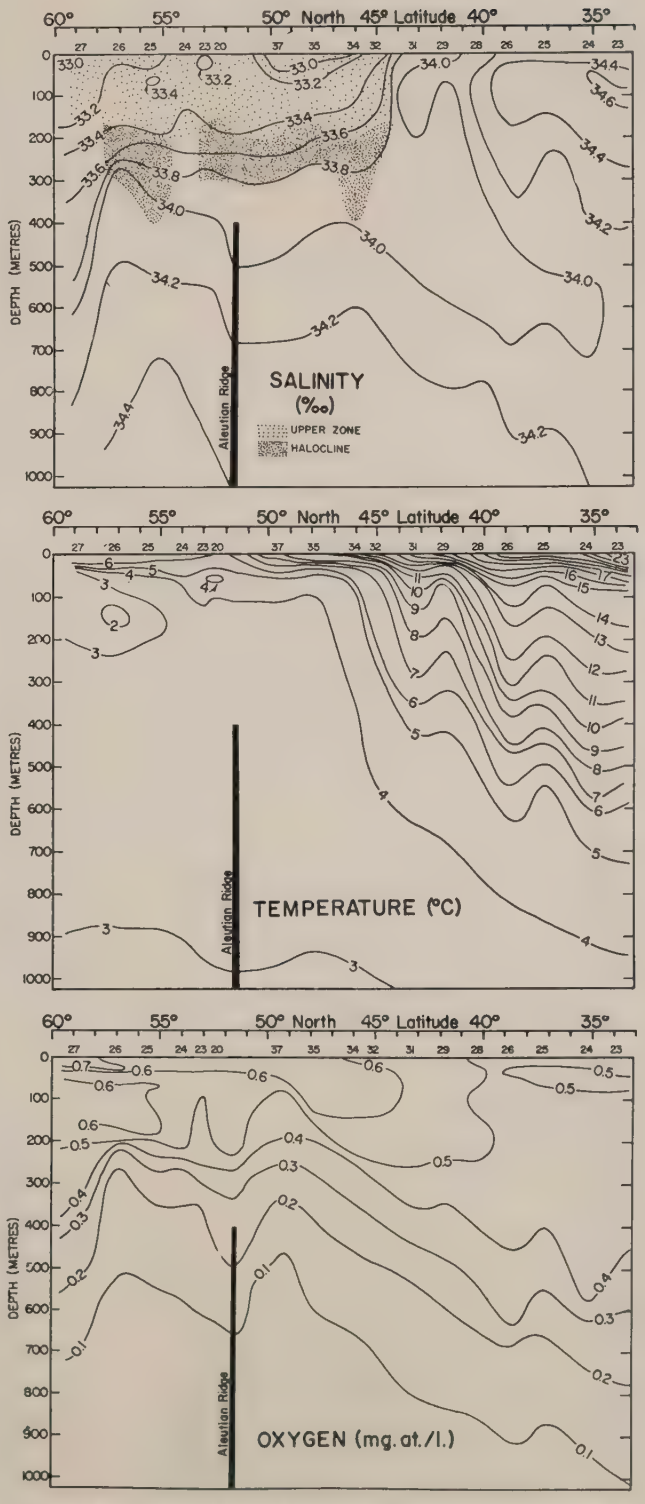


FIGURE 49. Vertical sections of salinity, temperature and dissolved oxygen along long. 180°, summer 1955.

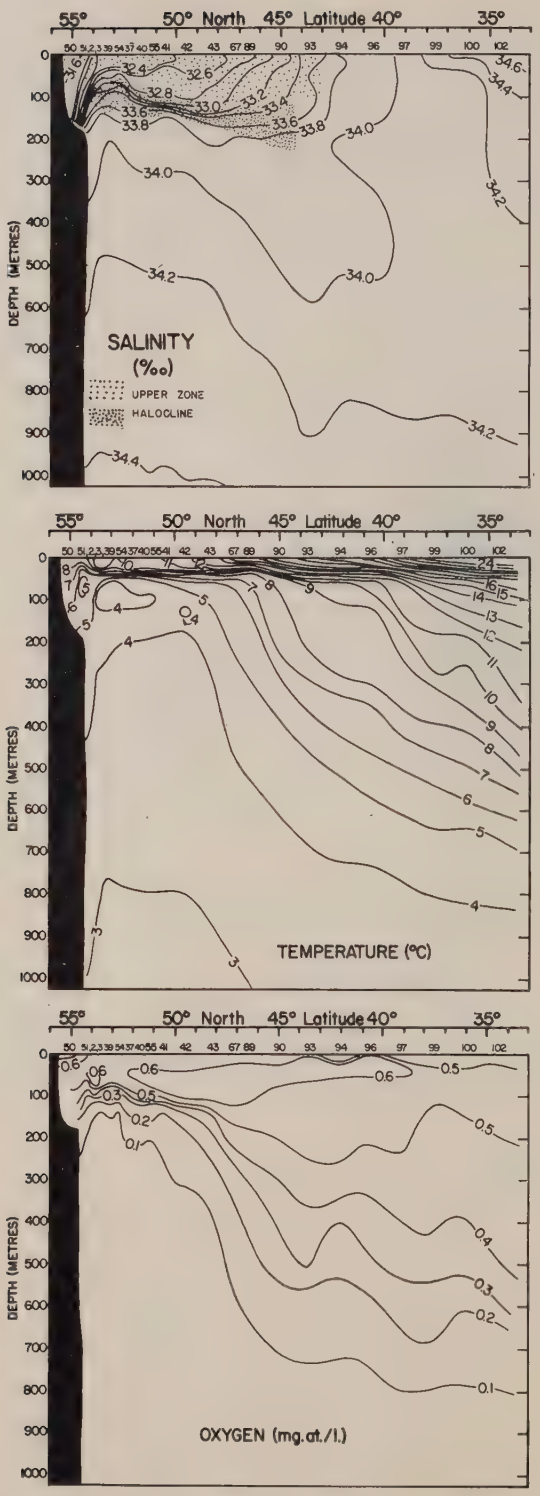


FIGURE 50. Vertical sections of salinity, temperature and dissolved oxygen along approx. long. 160°W., summer 1955.

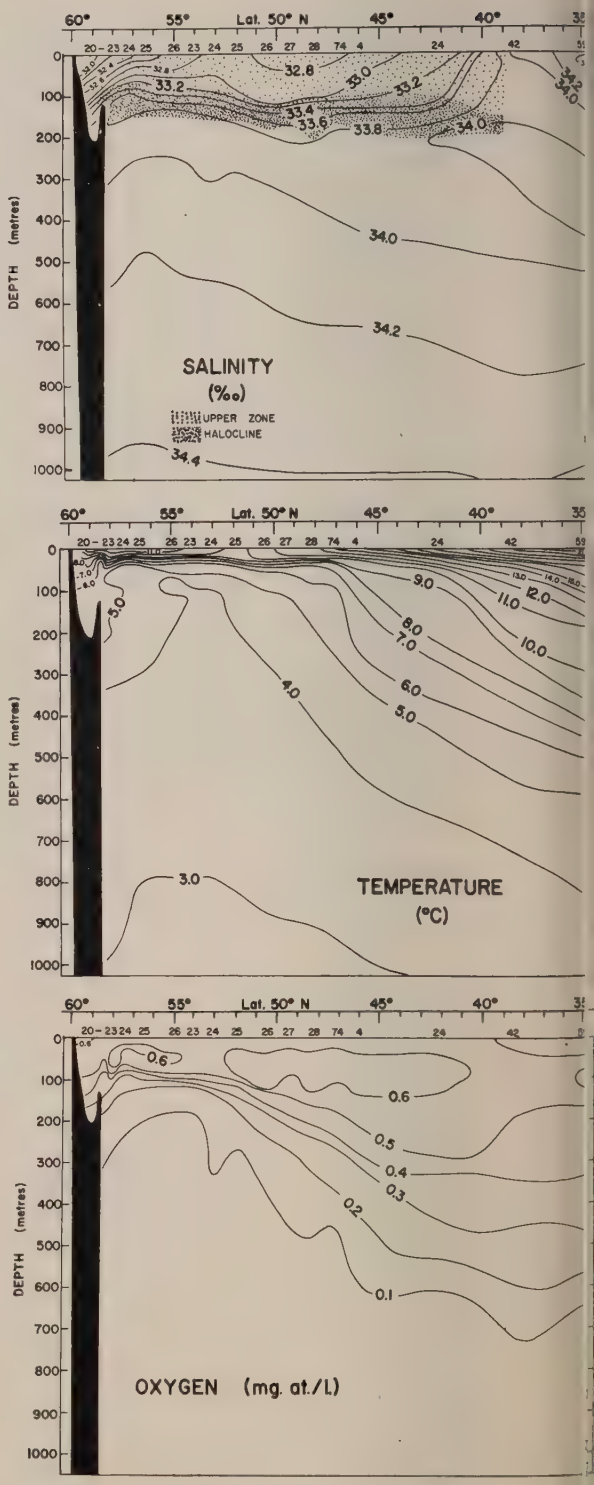
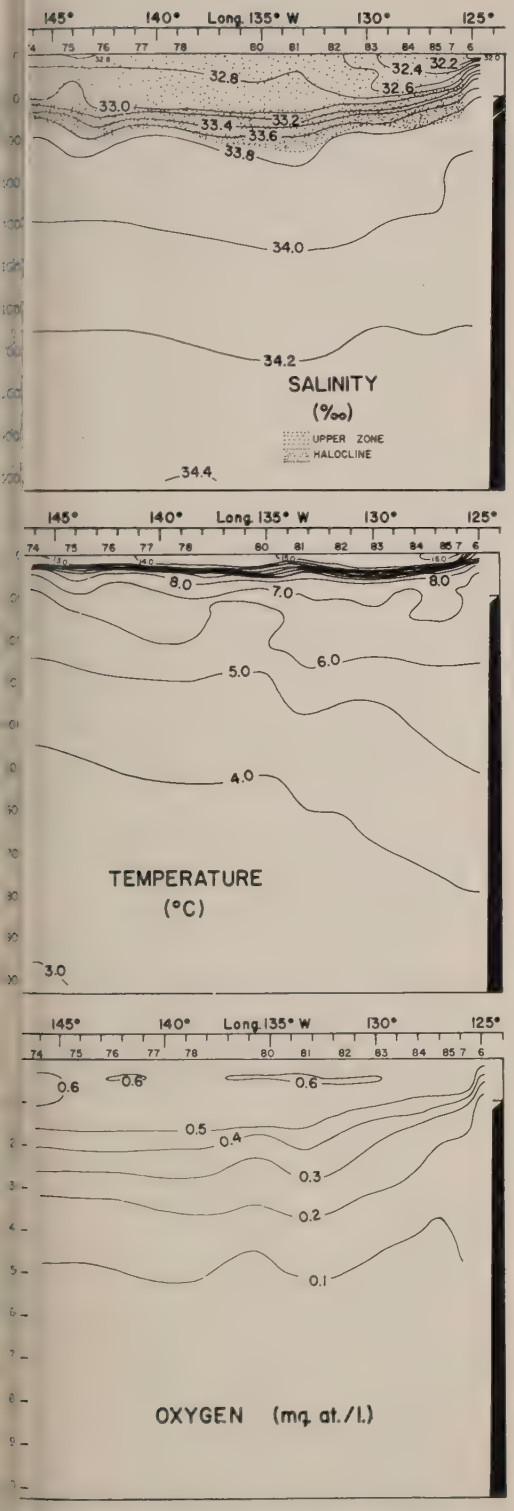


FIGURE 51. Vertical sections of salinity, temperature and dissolv oxygen along approx. long. 148°W., summer 1955.



52. Vertical sections of salinity, temperature and dissolved oxygen along approx. lat. 47°N., summer 1955.

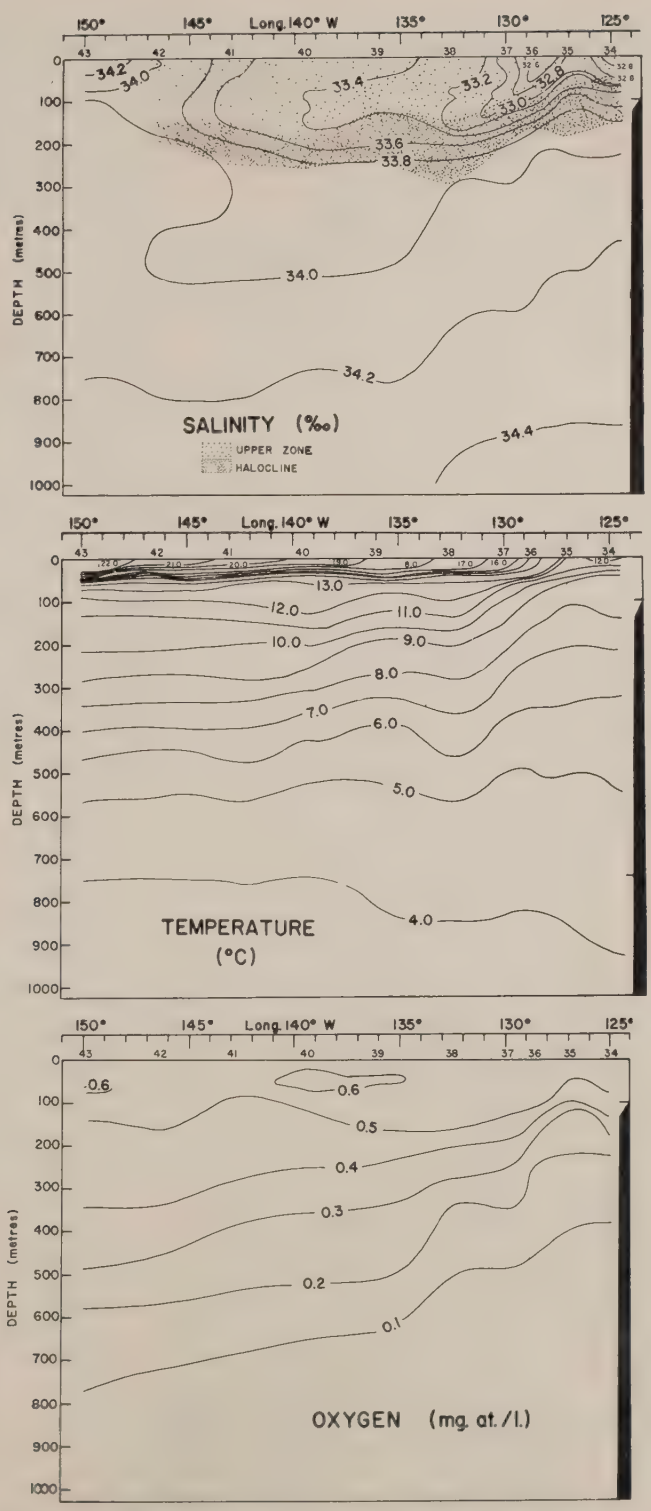


FIGURE 53. Vertical sections of salinity, temperature and dissolved oxygen along approx. lat. 39°N., summer 1955.

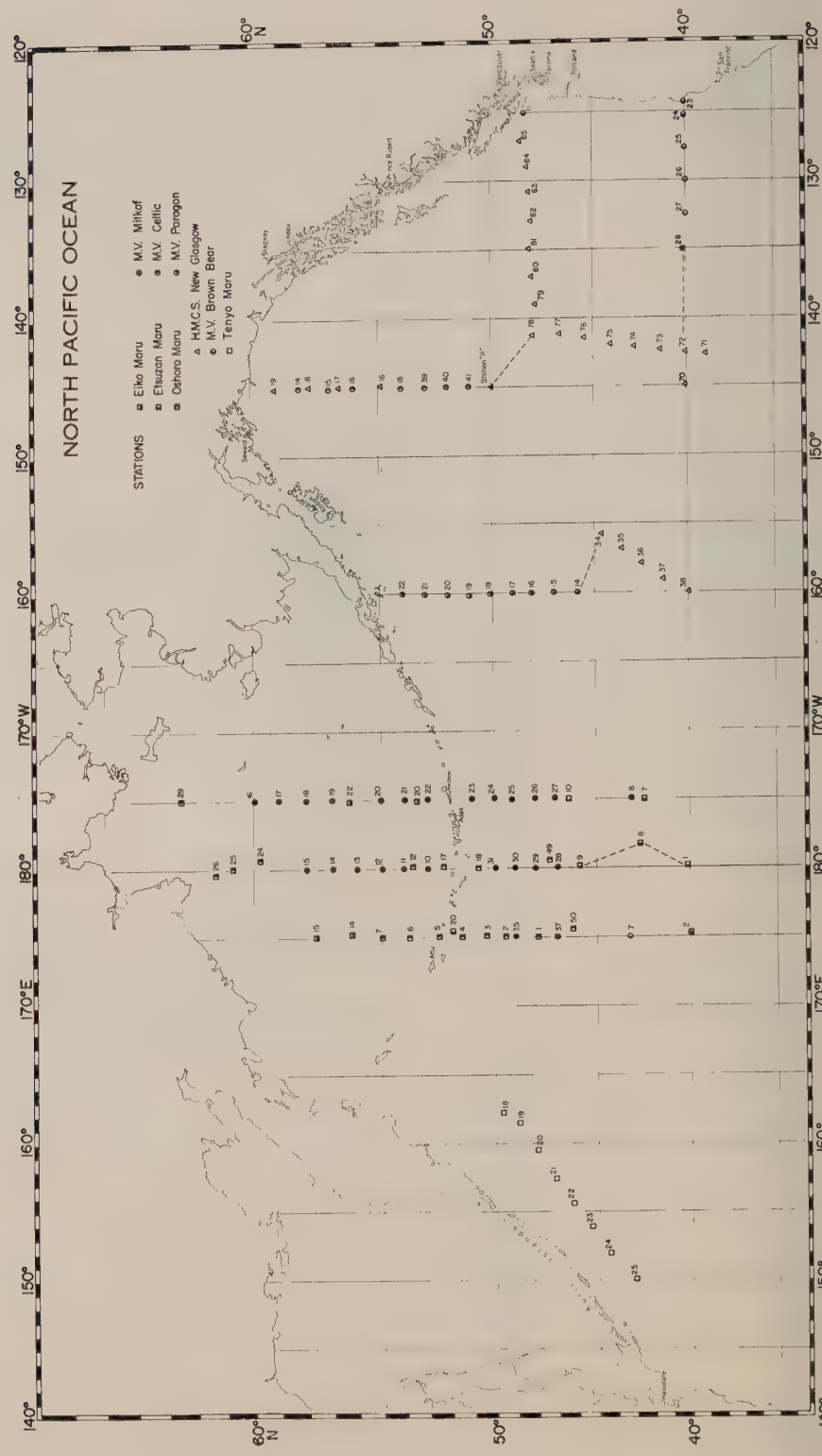


FIGURE 54. Locations of vertical sections, summer 1956.

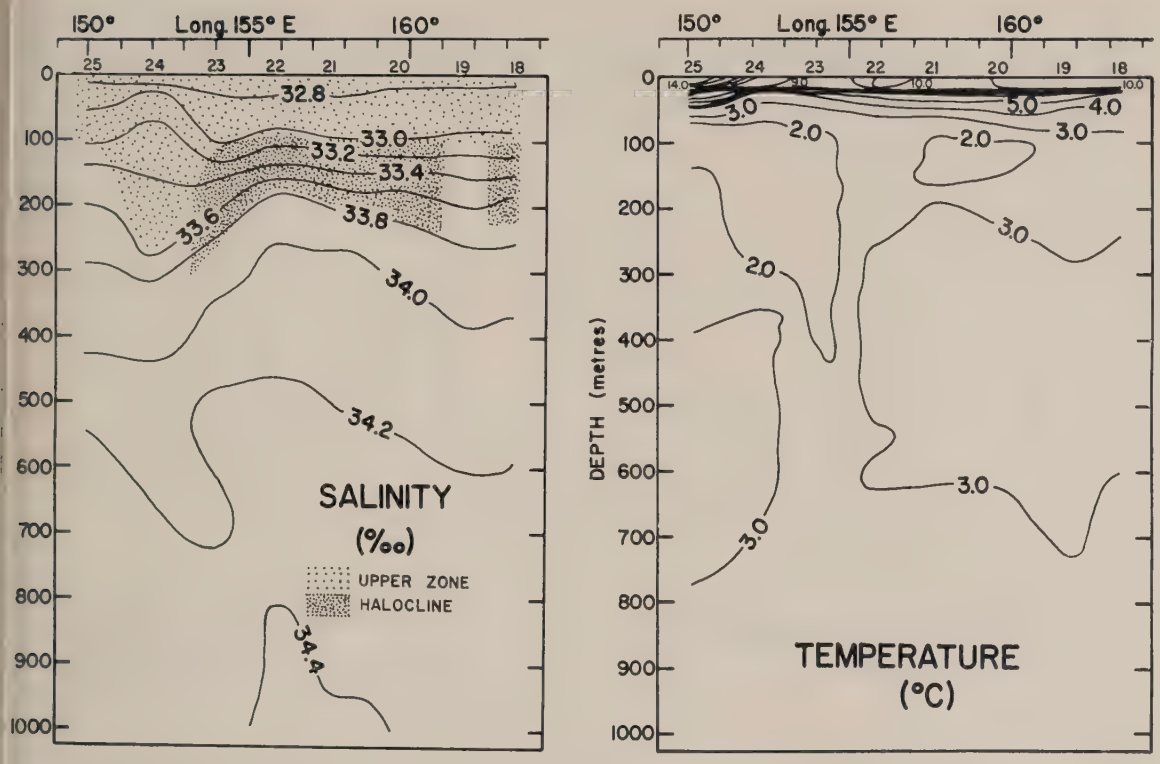


FIGURE 55. Vertical sections of salinity and temperature along Kuril Islands, summer 1956.

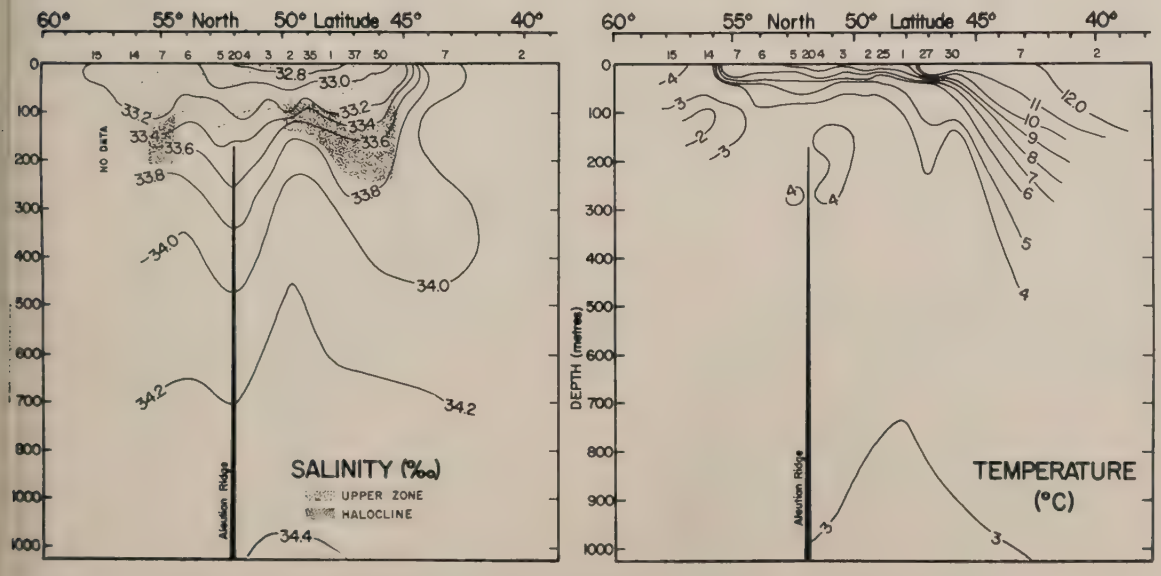


FIGURE 56. Vertical sections of salinity and temperature along long. 175°E., summer 1956.

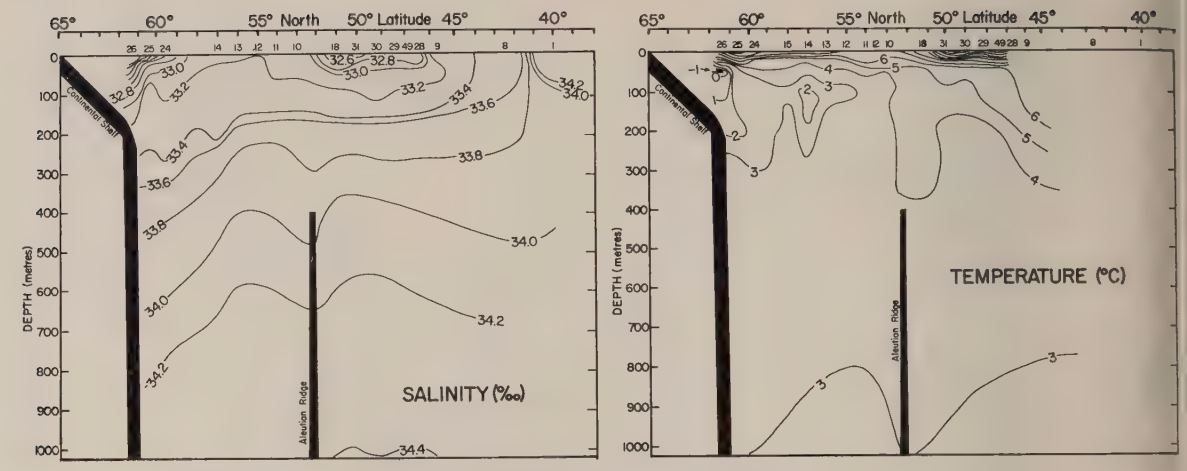


FIGURE 57. Vertical sections of salinity and temperature along long. 180°, summer 1956.

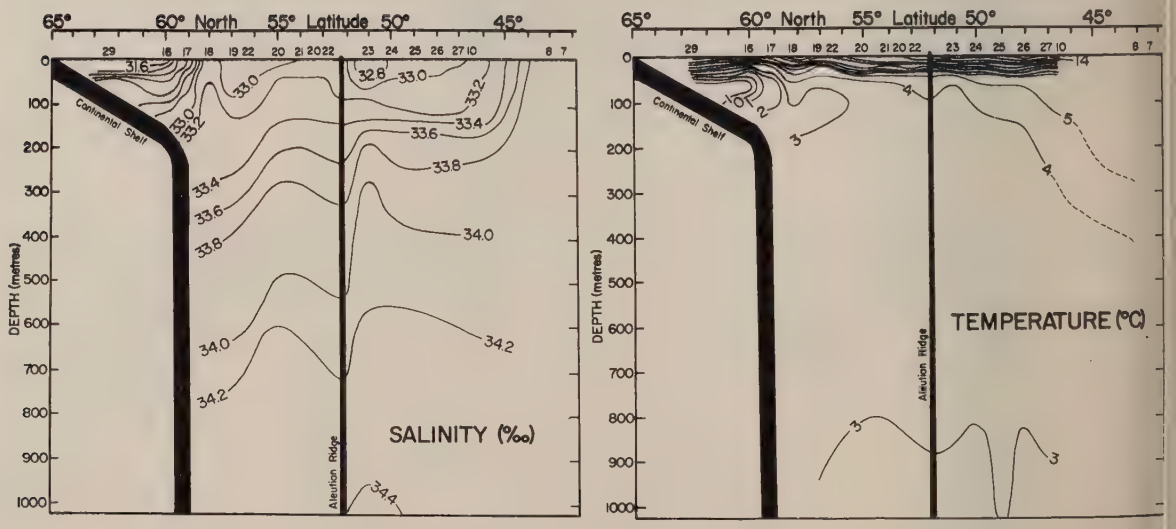


FIGURE 58. Vertical sections of salinity and temperature along long. 175°W., summer 1956.

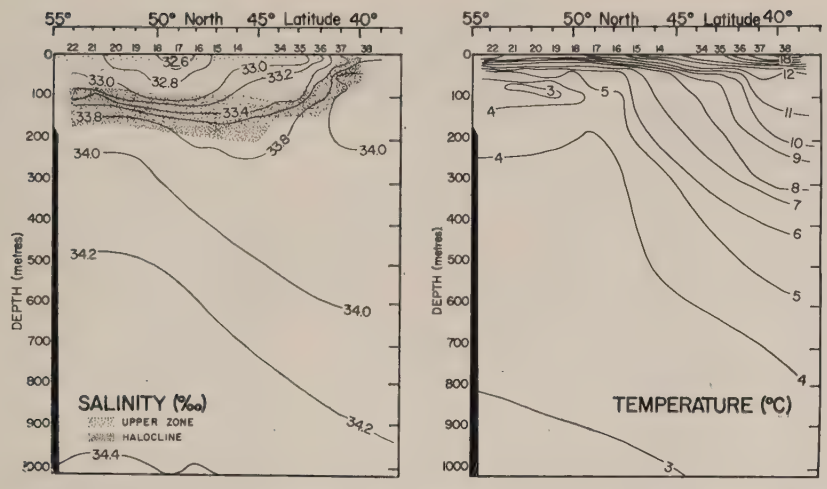


FIGURE 59. Vertical sections of salinity and temperature along long. 160°W., summer 1956.

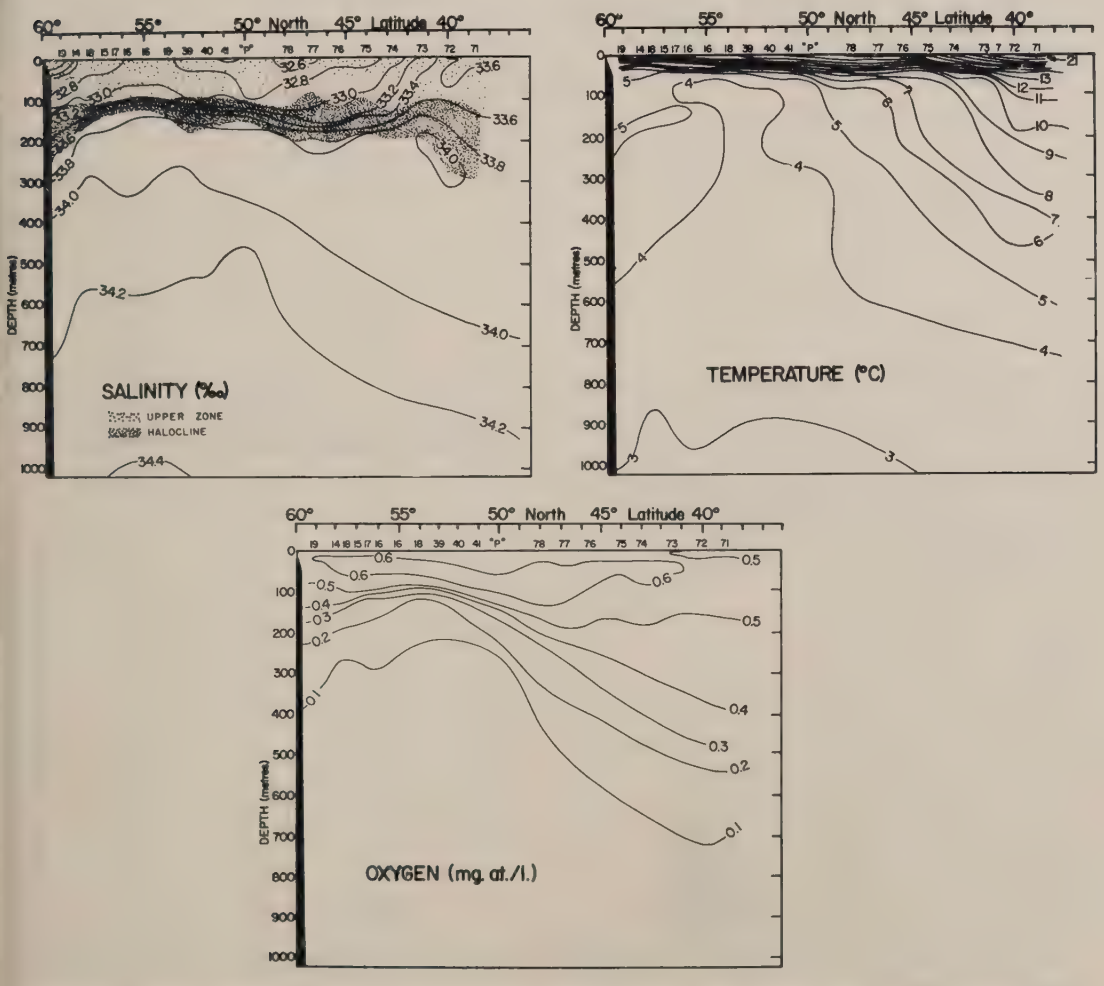


FIGURE 60. Vertical sections of salinity, temperature and dissolved oxygen along approx. long. 145° W., summer 1956.

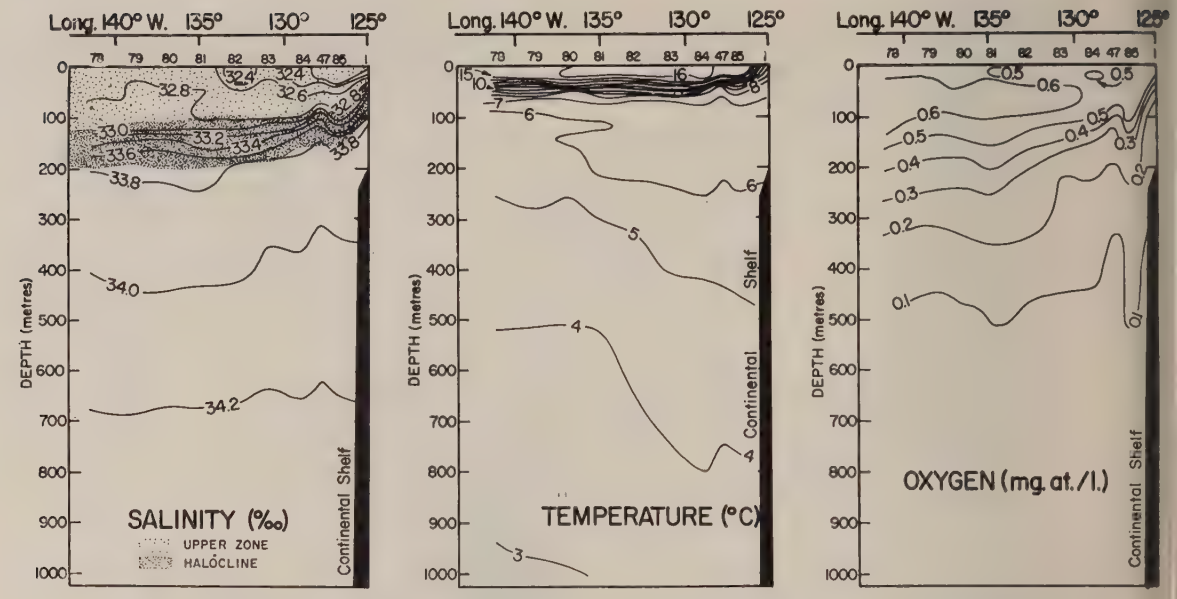


FIGURE 61. Vertical sections of salinity, temperature and dissolved oxygen along approx. lat. 48°N., summer 1956.

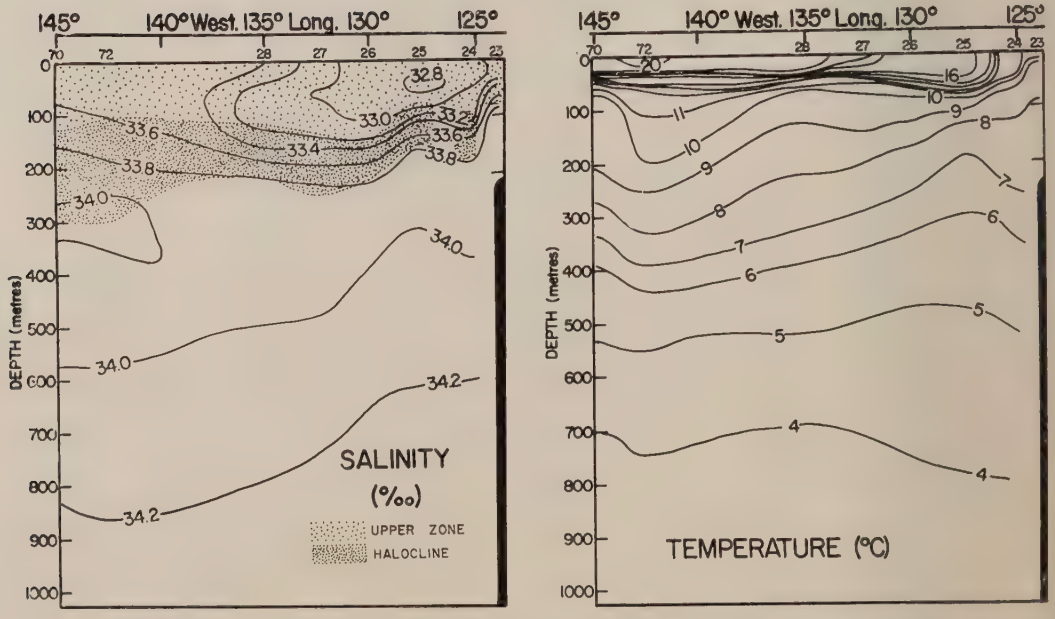


FIGURE 62. Vertical sections of salinity and temperature along lat. 40°N., summer 1956.

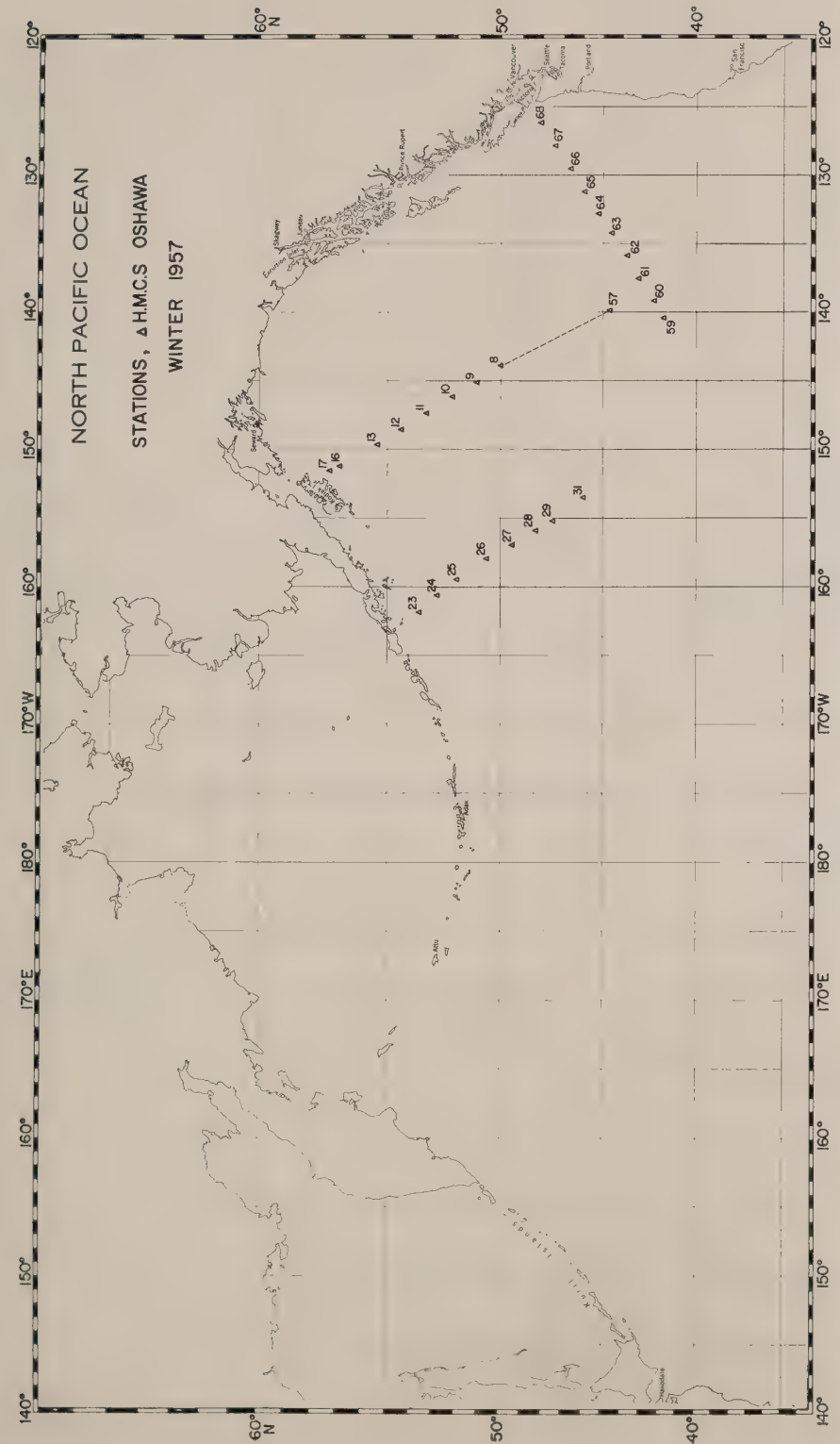


FIGURE 63. Locations of vertical sections, winter 1957.

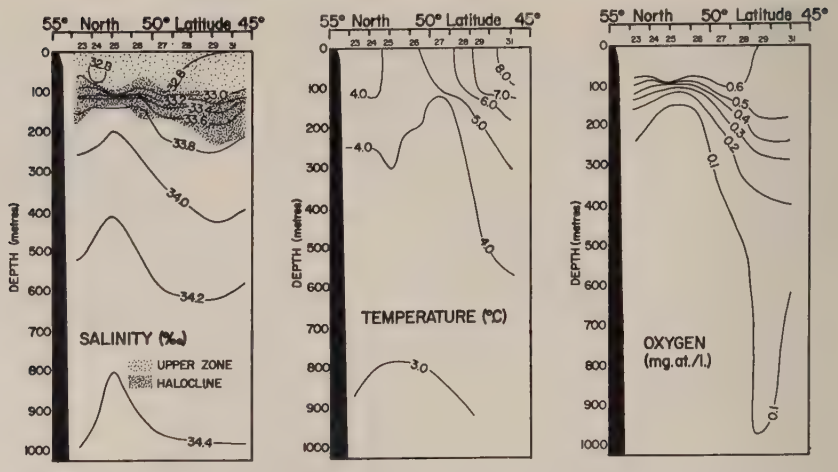


FIGURE 64. Vertical sections of salinity, temperature and dissolved oxygen along approx. long. 157°W., winter 1957.

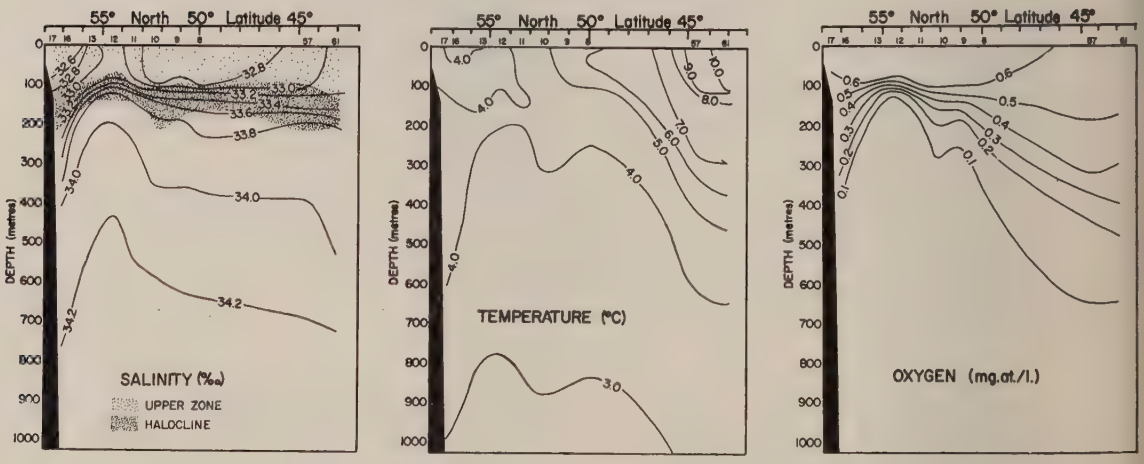


FIGURE 65. Vertical sections of salinity, temperature and dissolved oxygen along approx. long. 147°W., winter 1957.

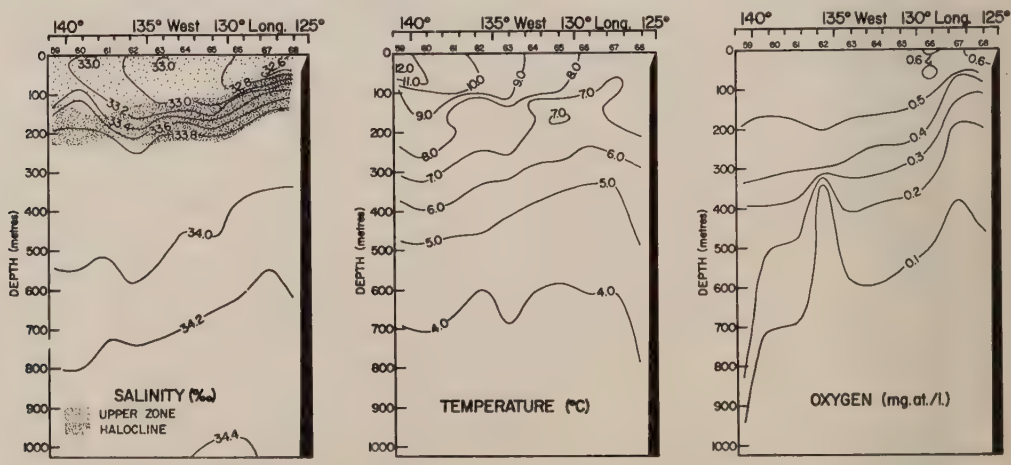


FIGURE 66. Vertical sections of salinity, temperature and dissolved oxygen from lat. 41°N., long. 140°W. to Vancouver Island, winter 1957.

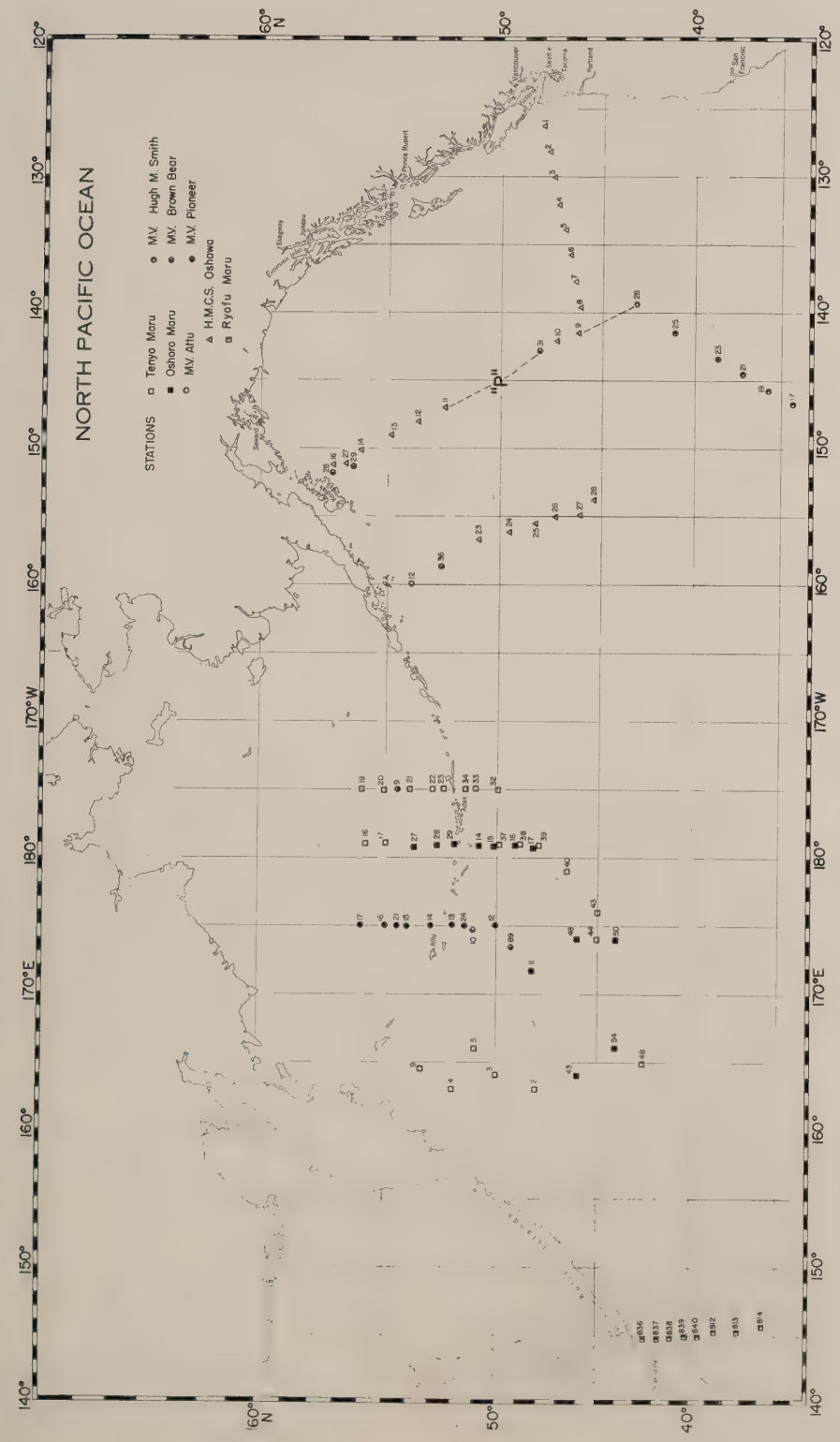


FIGURE 67. Locations of vertical sections, summer 1957.

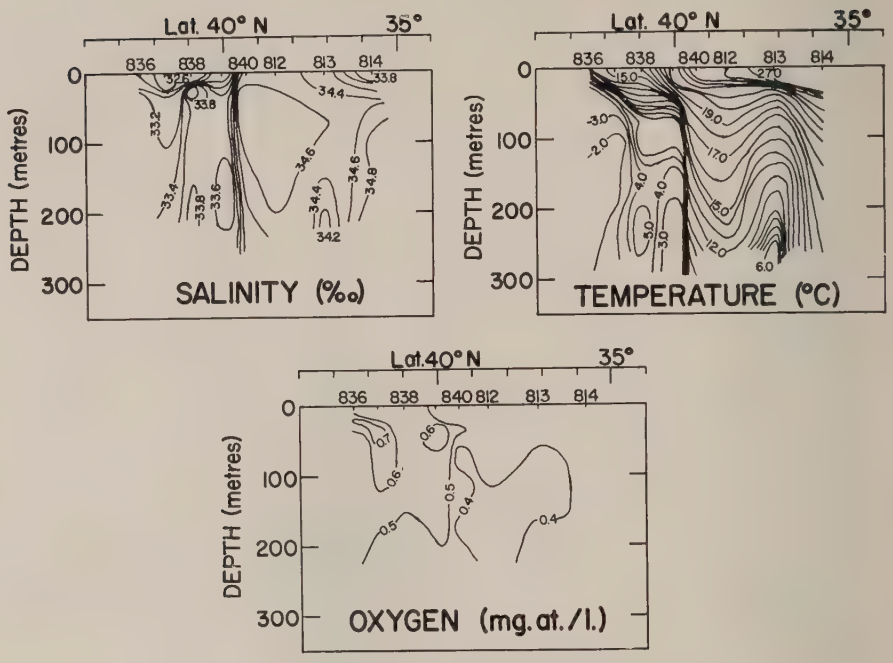


FIGURE 68. Vertical sections of salinity, temperature and dissolved oxygen along long. 145°E., summer 1957.

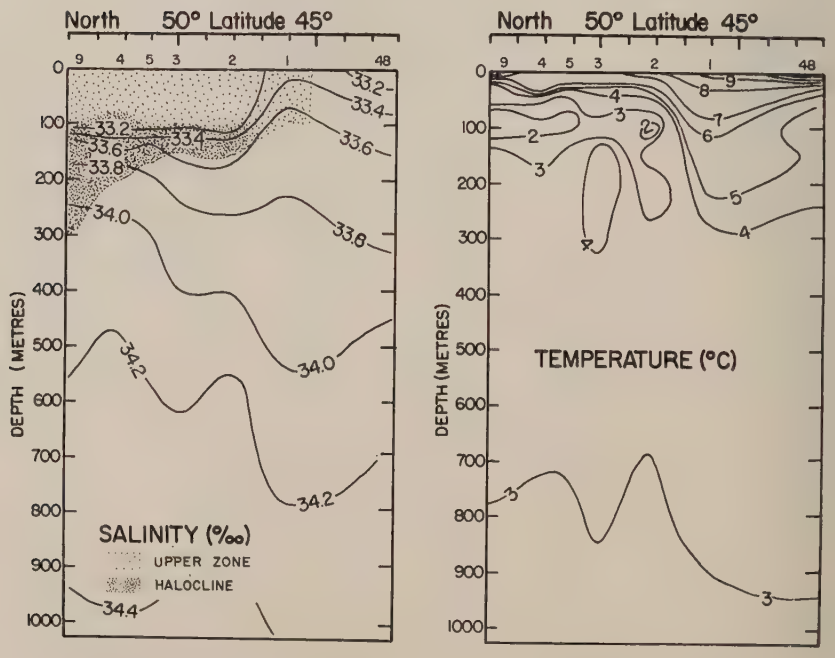


FIGURE 69. Vertical sections of salinity and temperature along approx. long. 165°E., summer 1957.

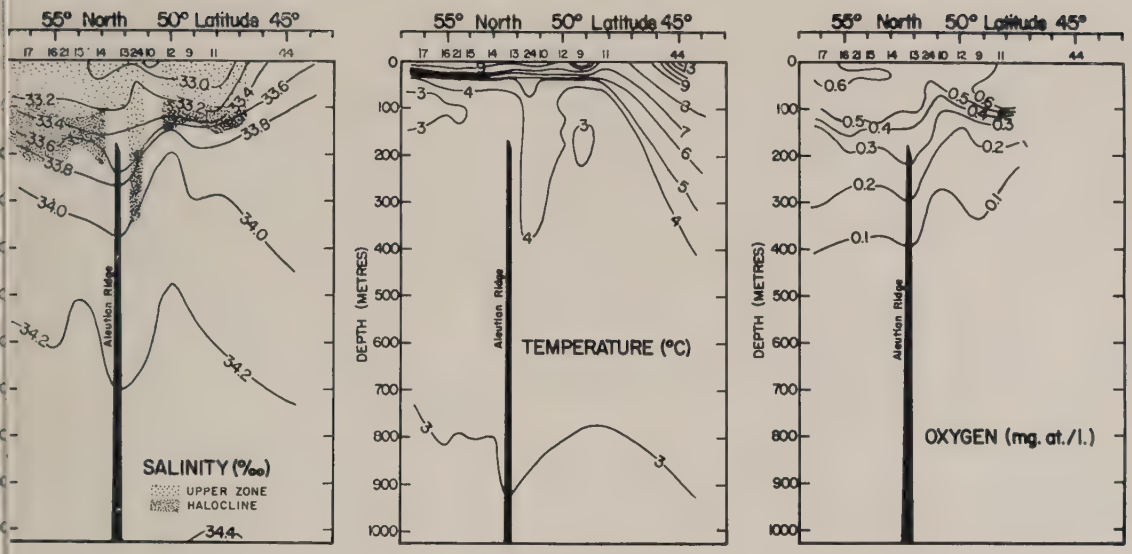


FIGURE 70. Vertical sections of salinity, temperature and dissolved oxygen along long. 175°E., summer 1957.

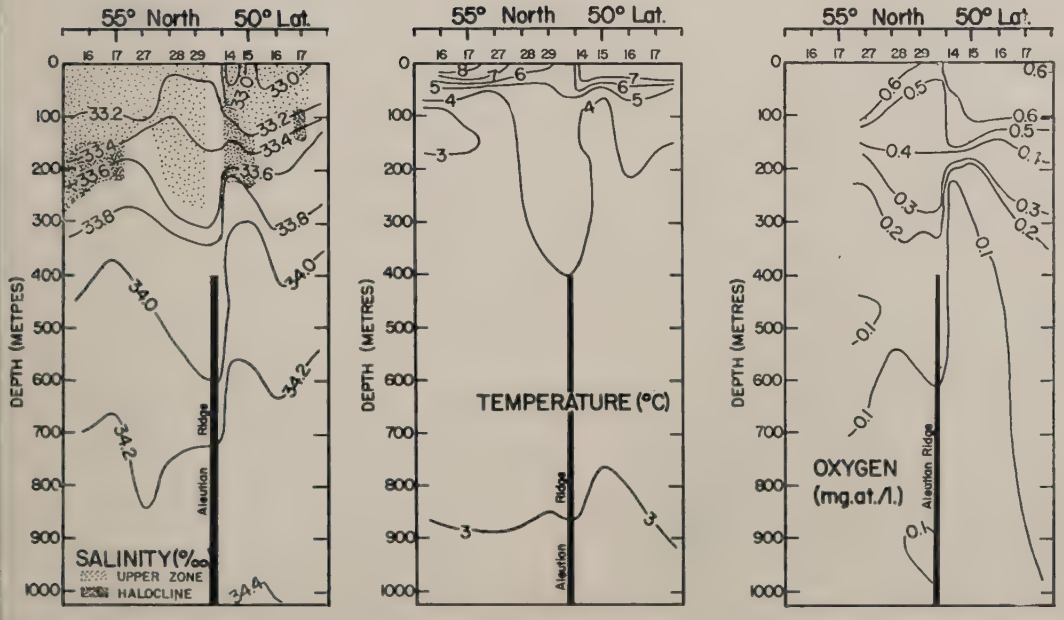


FIGURE 71. Vertical sections of salinity, temperature and dissolved oxygen along approx. long. 180 , summer 1957.

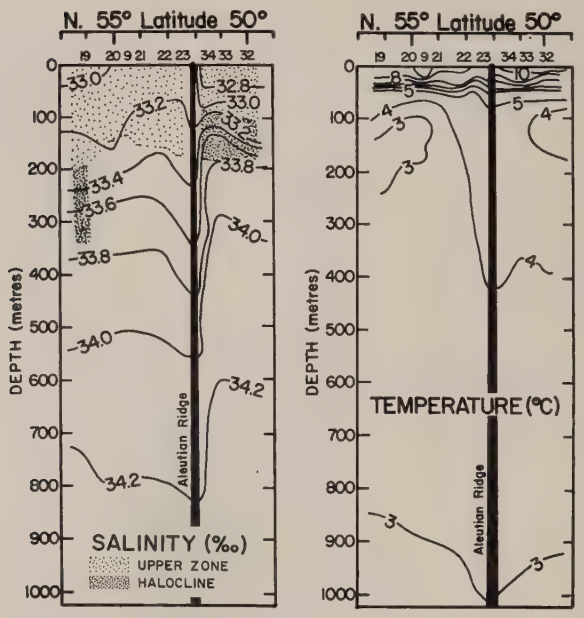


FIGURE 72. Vertical sections of salinity and temperature along long. 175°W., summer 1957.

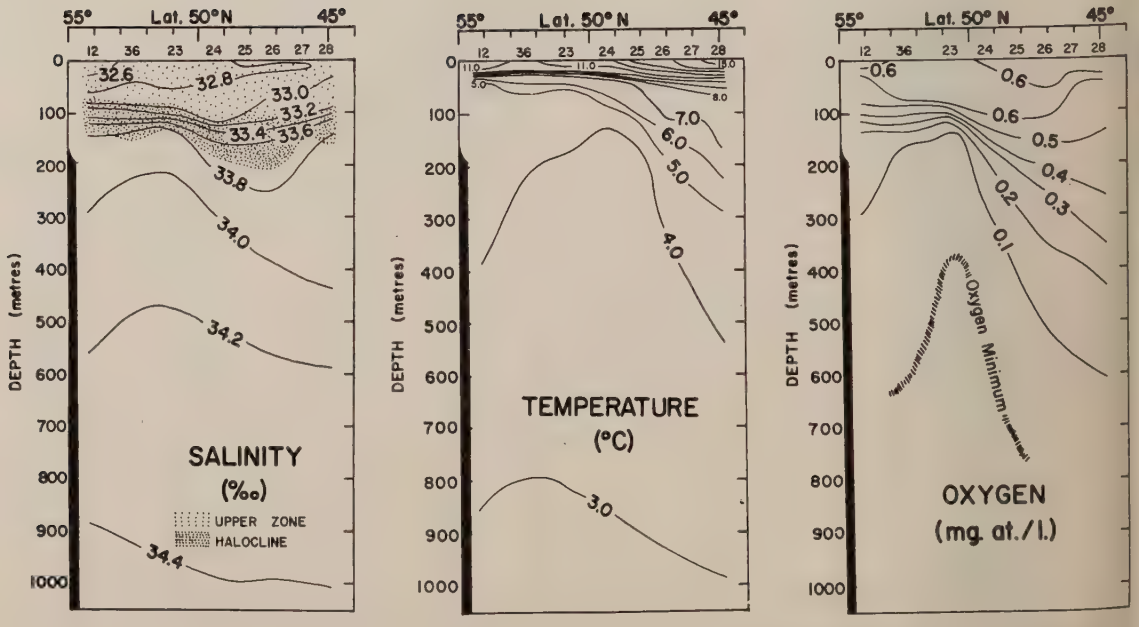


FIGURE 73. Vertical sections of salinity, temperature and dissolved oxygen along approx. long. 160°W., summer 1957.

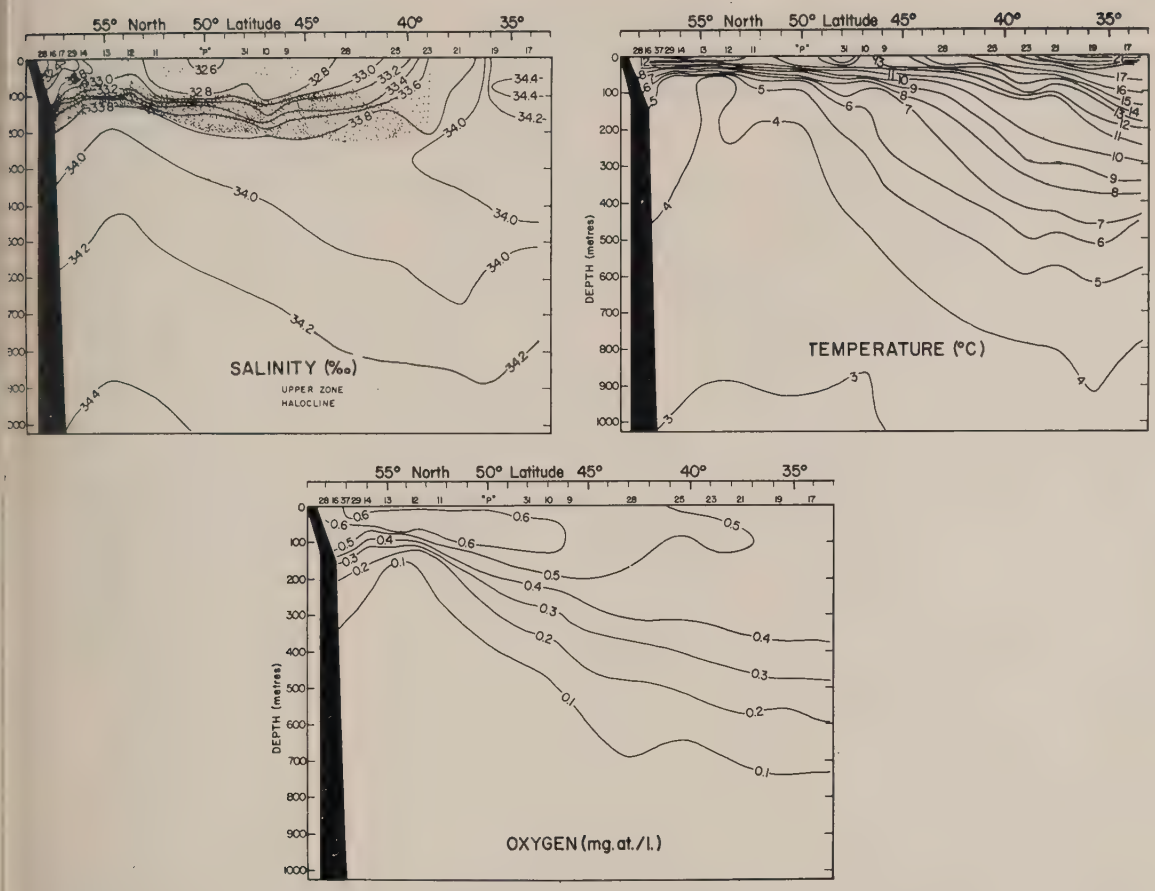


FIGURE 74. Vertical sections of salinity, temperature and dissolved oxygen along approx. long. 145°W., summer 1957.

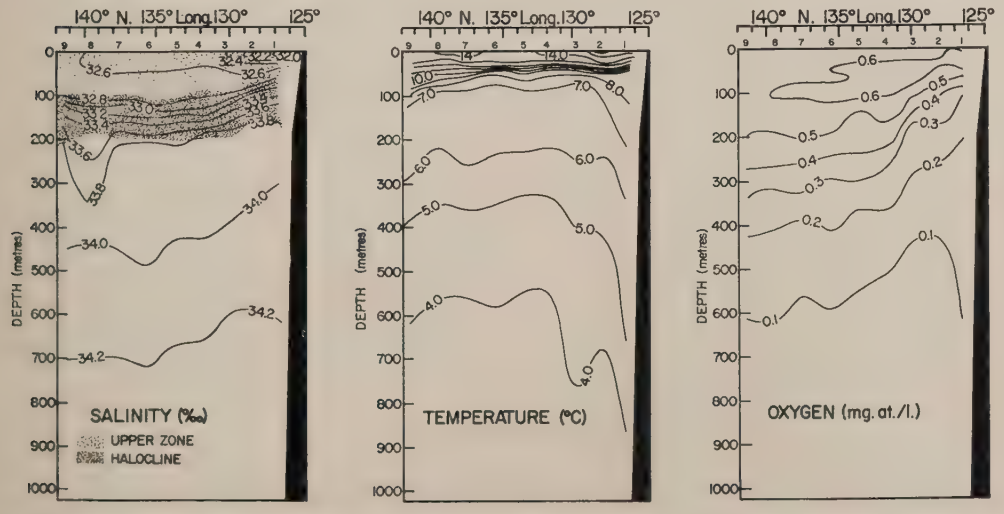


FIGURE 75. Vertical sections of salinity, temperature and dissolved oxygen along approx. lat. 47°N., summer 1957.

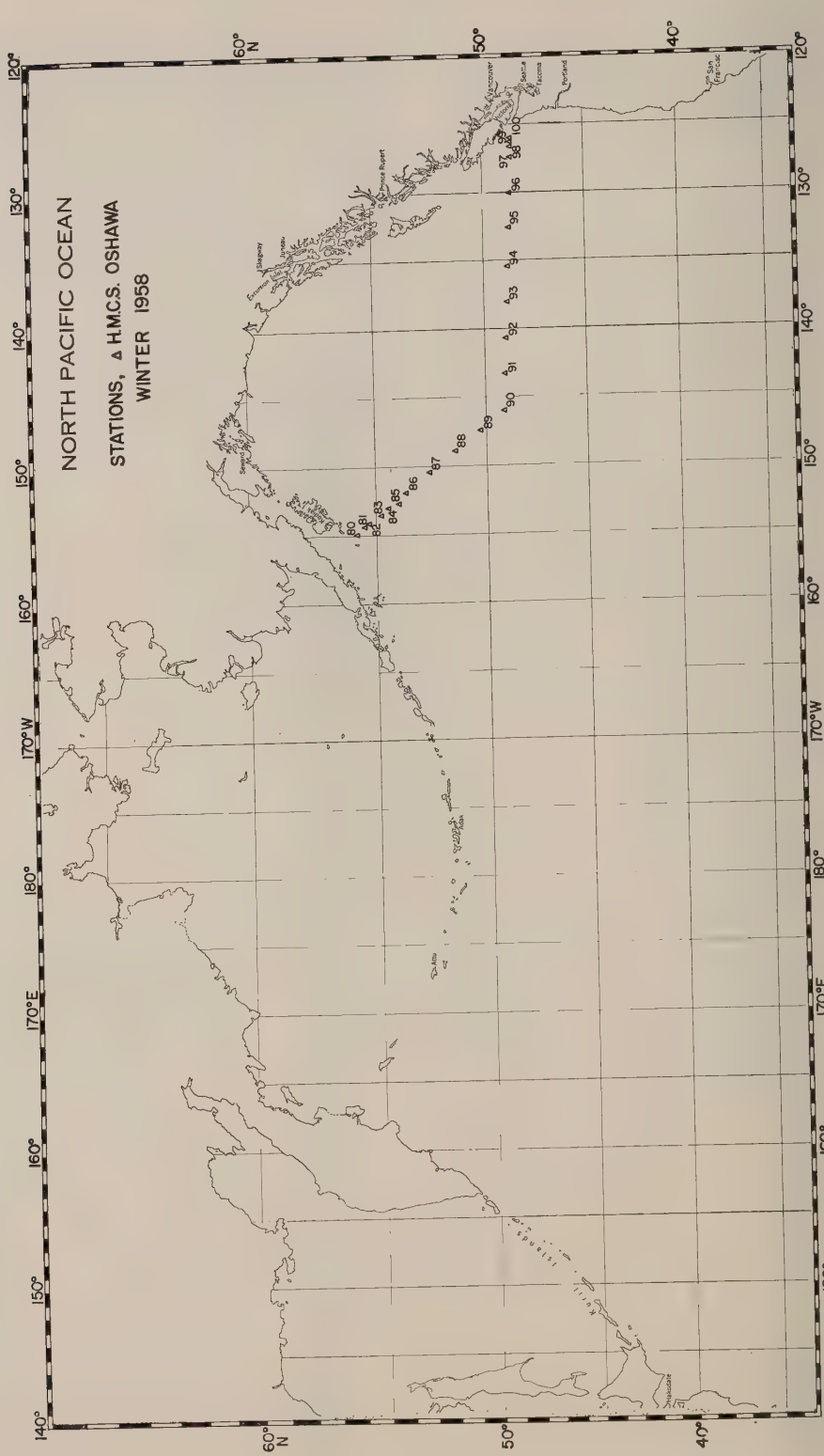


FIGURE 76. Locations of vertical sections, winter 1958.

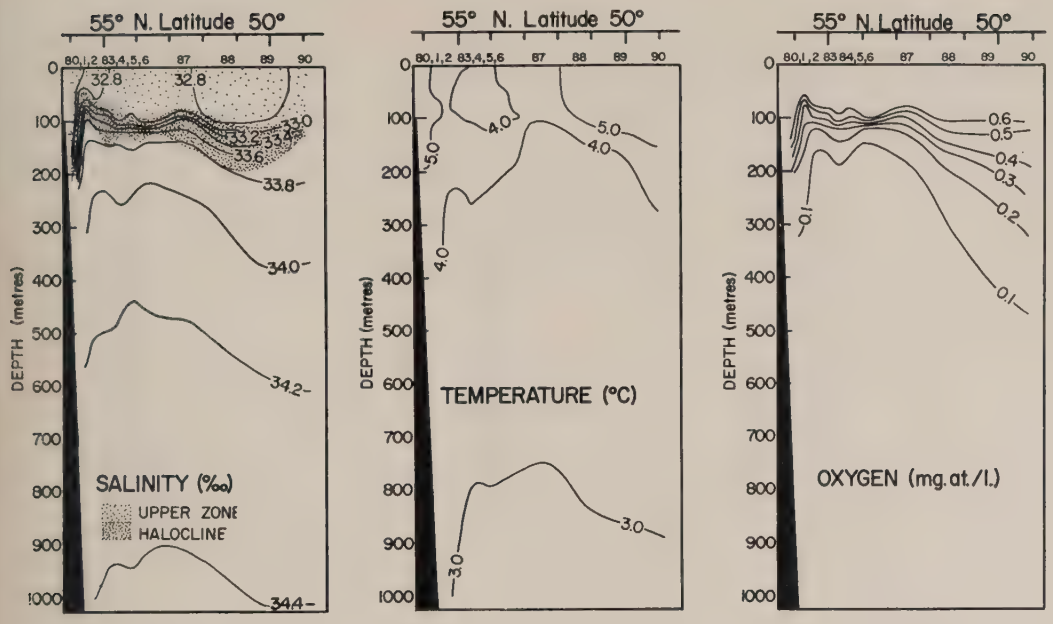


FIGURE 77. Vertical sections of salinity, temperature and dissolved oxygen along approx. long. 150°W., winter 1958.

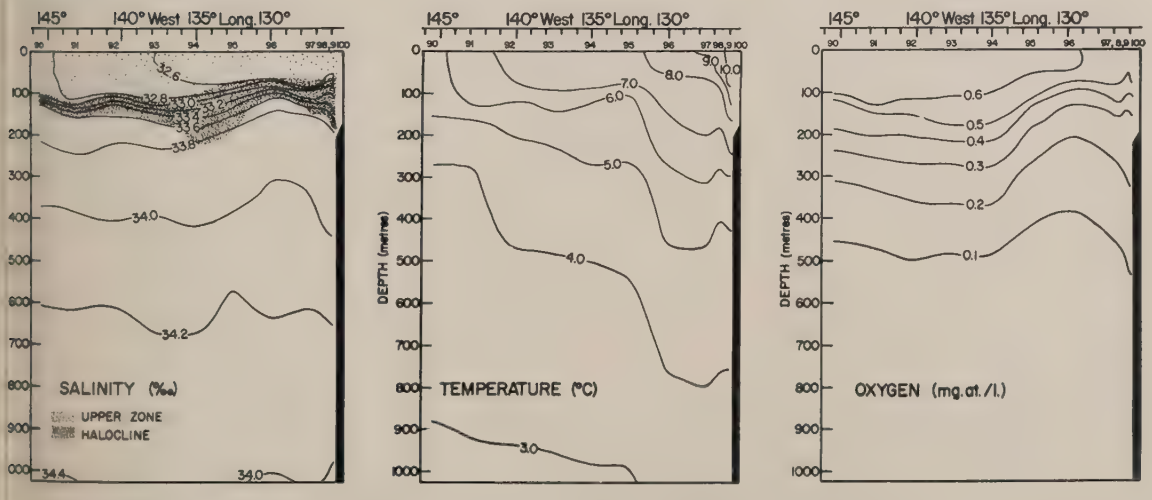


FIGURE 78. Vertical sections of salinity, temperature and dissolved oxygen along approx. lat. 49°N., winter 1958.

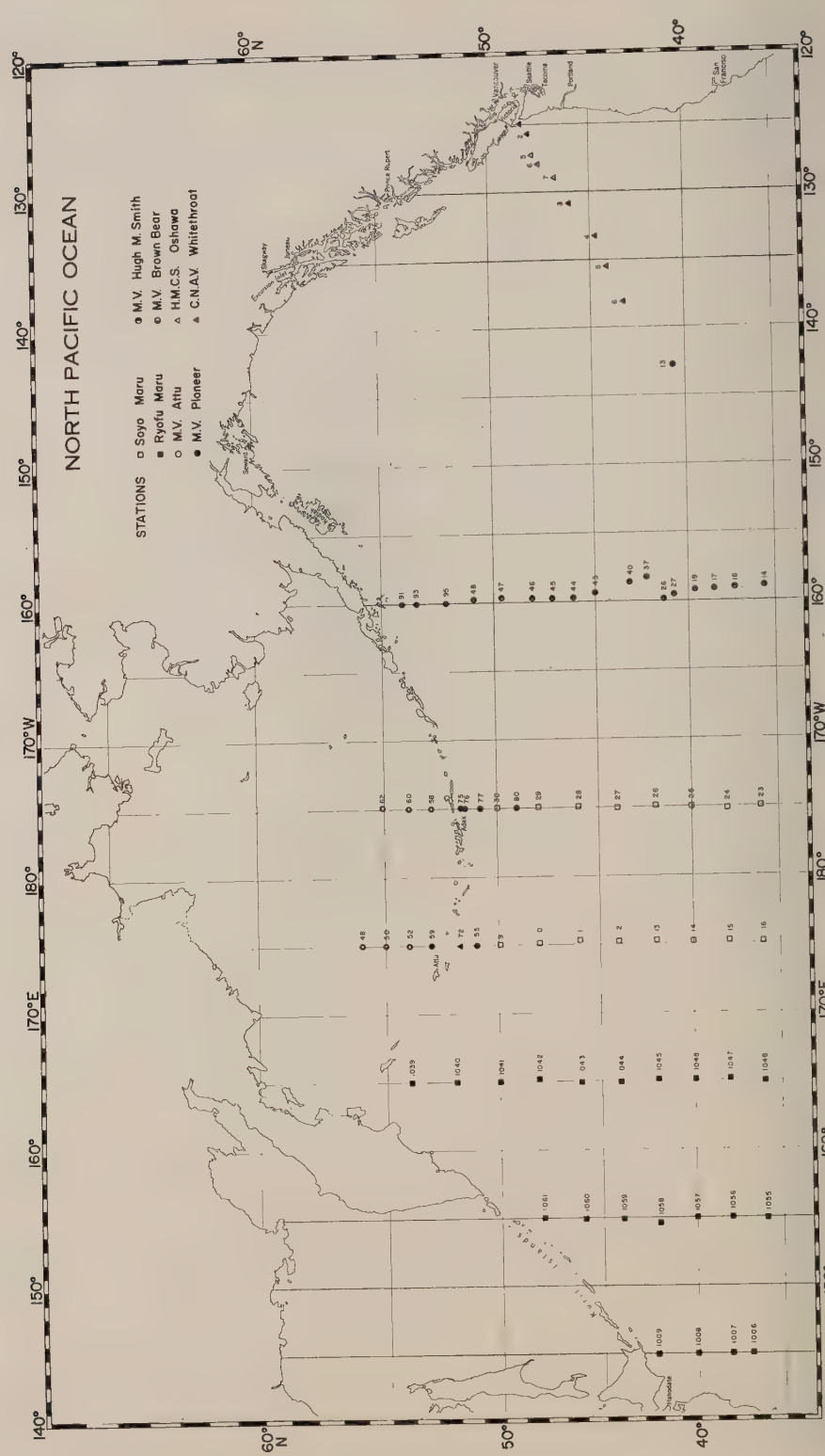


FIGURE 79. Locations of vertical sections, summer 1958.

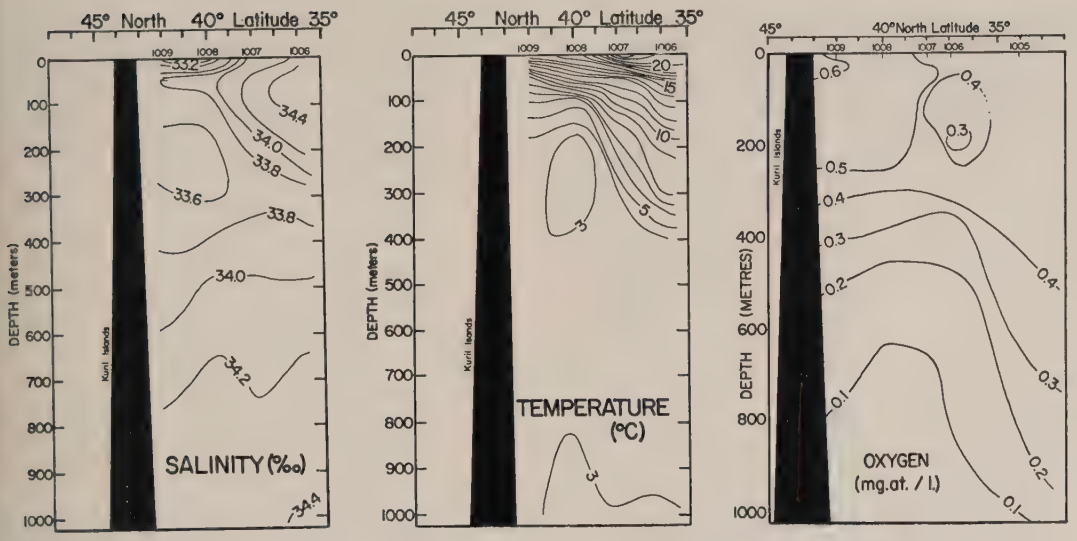


FIGURE 80. Vertical sections of salinity, temperature and dissolved oxygen along long. 145°E., summer 1958.

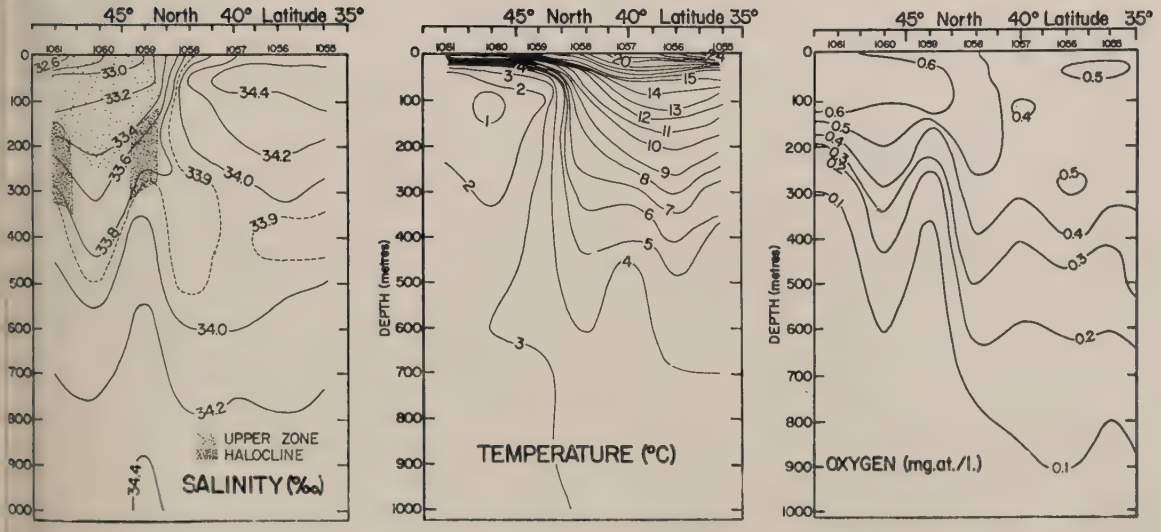


FIGURE 81. Vertical sections of salinity, temperature and dissolved oxygen along long. 155°E., summer 1958.

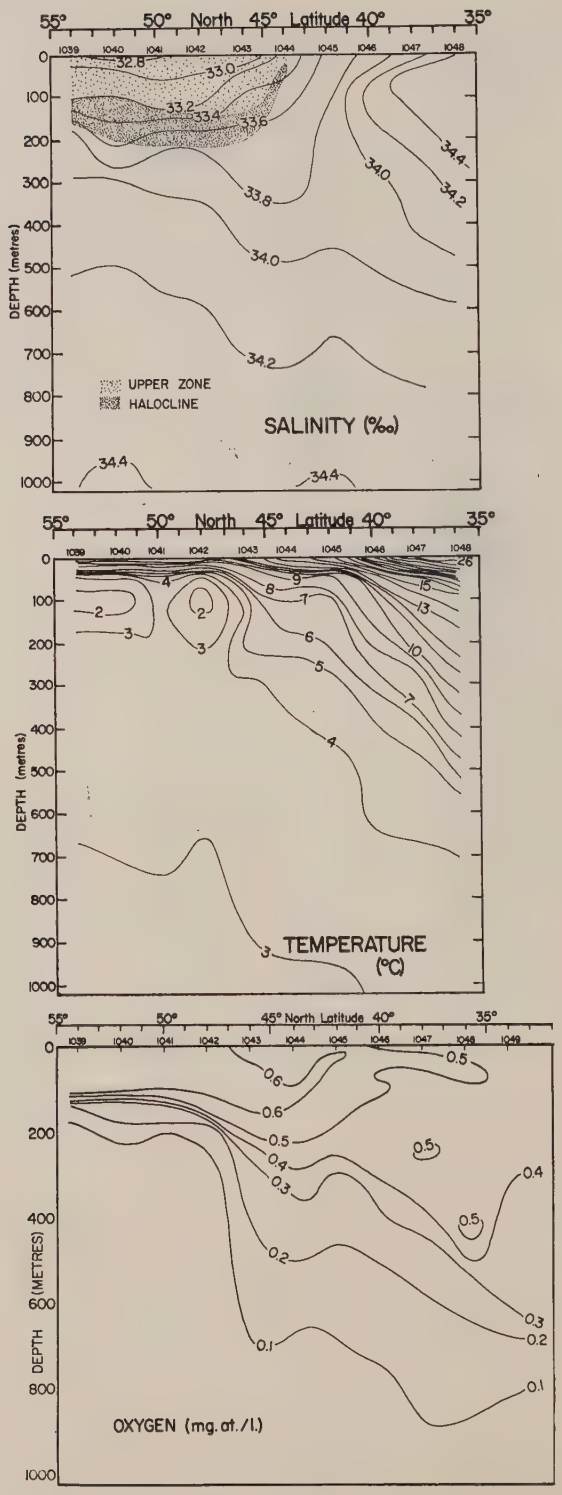


FIGURE 82. Vertical sections of salinity, temperature and dissolved oxygen along long. 165°E., summer 1958.

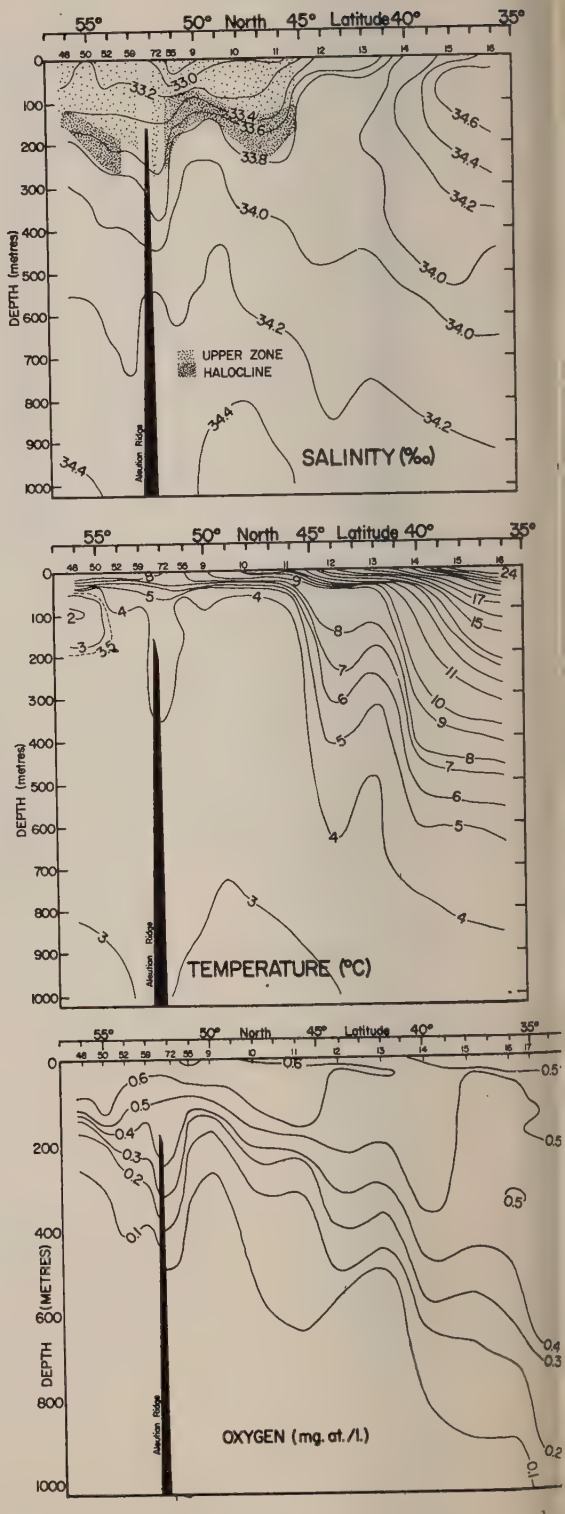
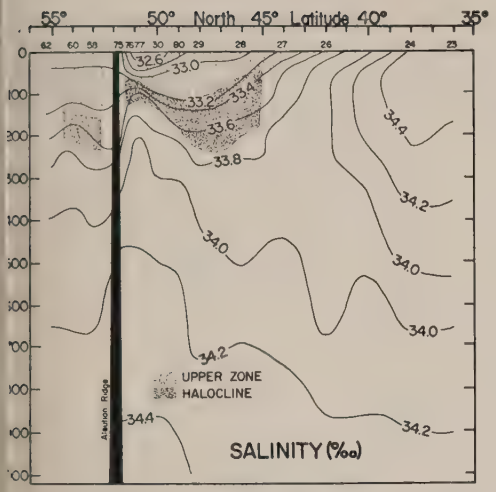
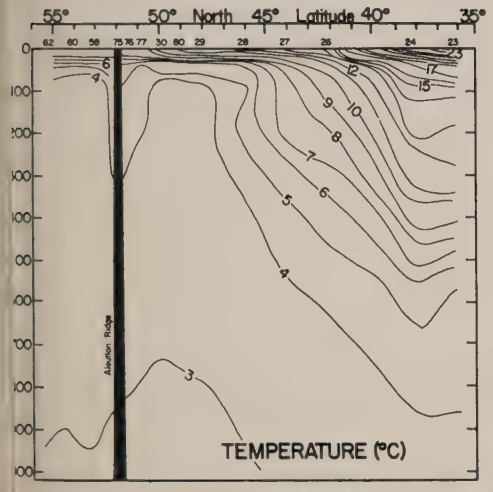


FIGURE 83. Vertical sections of salinity, temperature and dissolved oxygen along long. 175°E., summer 1958.





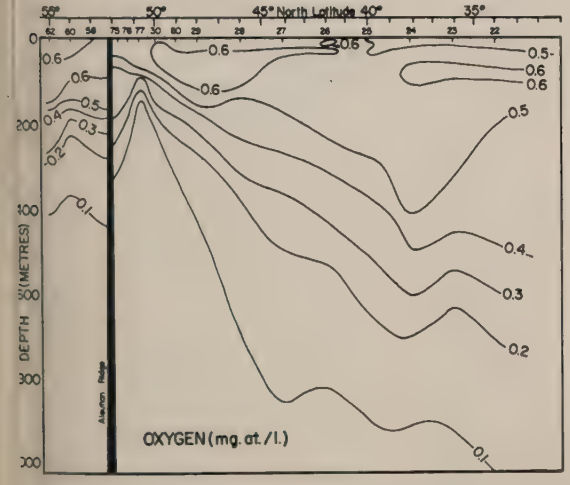
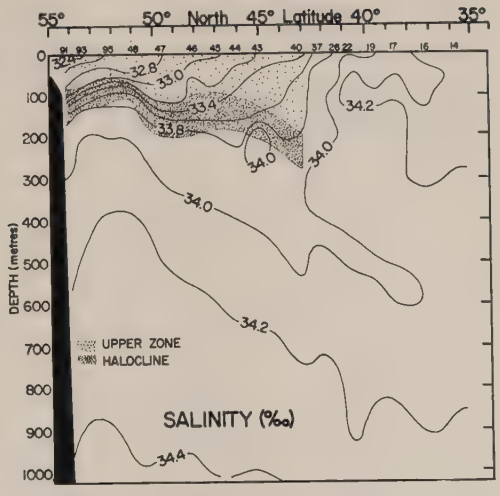
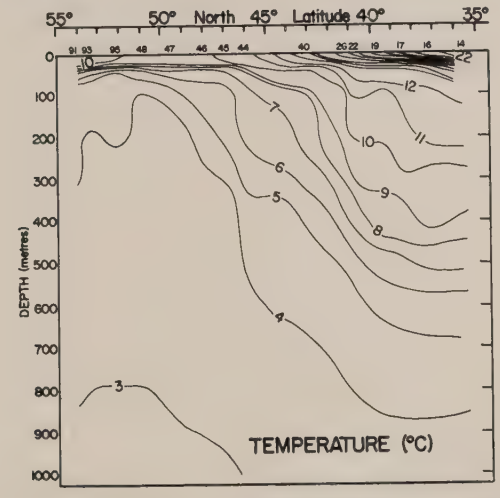


FIGURE 84. Vertical sections of salinity, temperature and dissolved oxygen along long. 175°W., summer 1958.





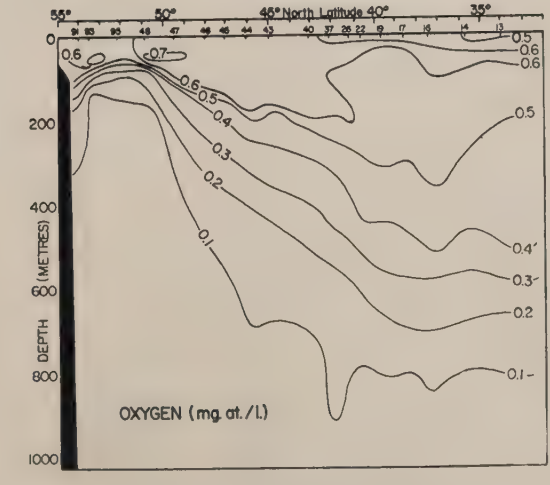


FIGURE 85. Vertical sections of salinity, temperature and dissolved oxygen along long. 160°W., summer 1958.

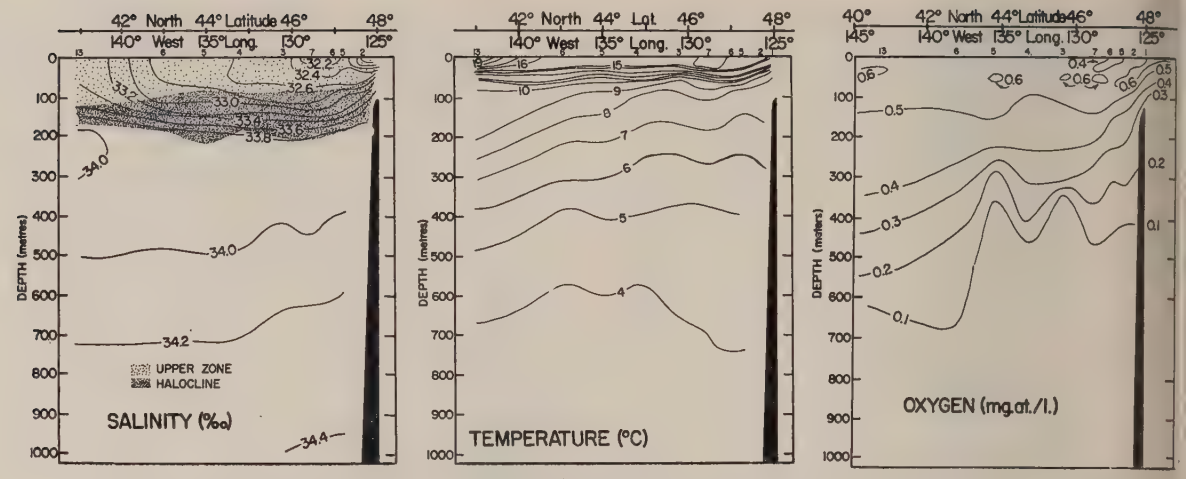


FIGURE 86. Vertical sections of salinity, temperature and dissolved oxygen along approx. lat. 45°N., summer 1958.

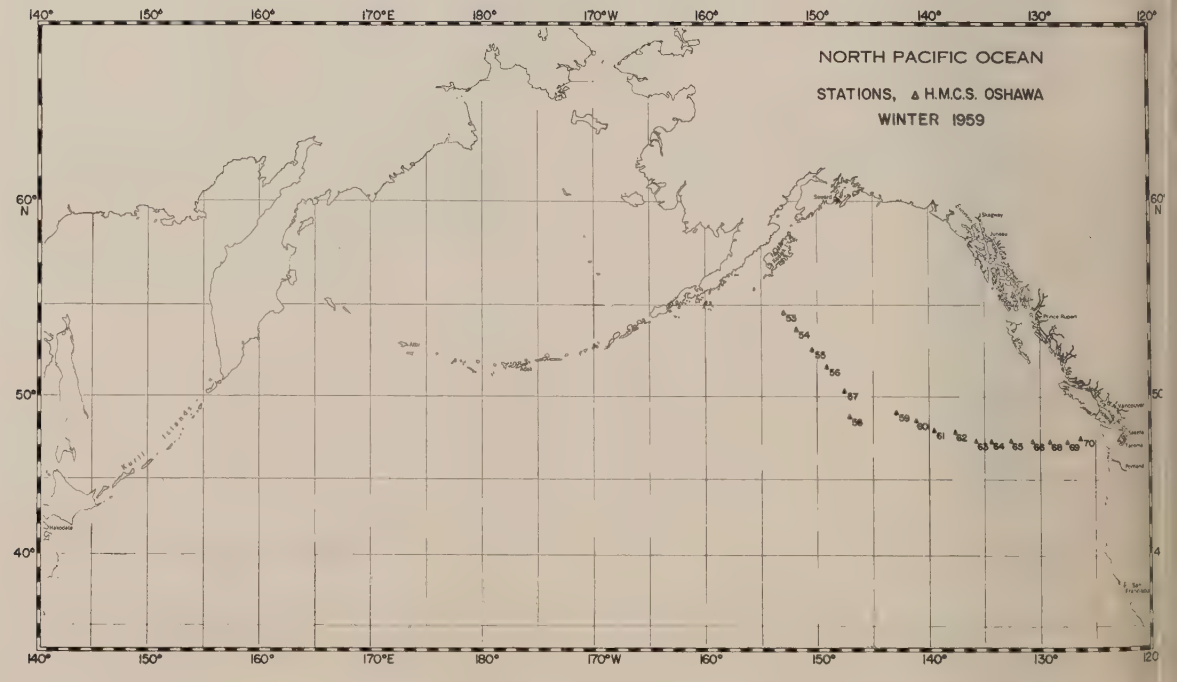


FIGURE 87. Locations of vertical sections, winter 1959.

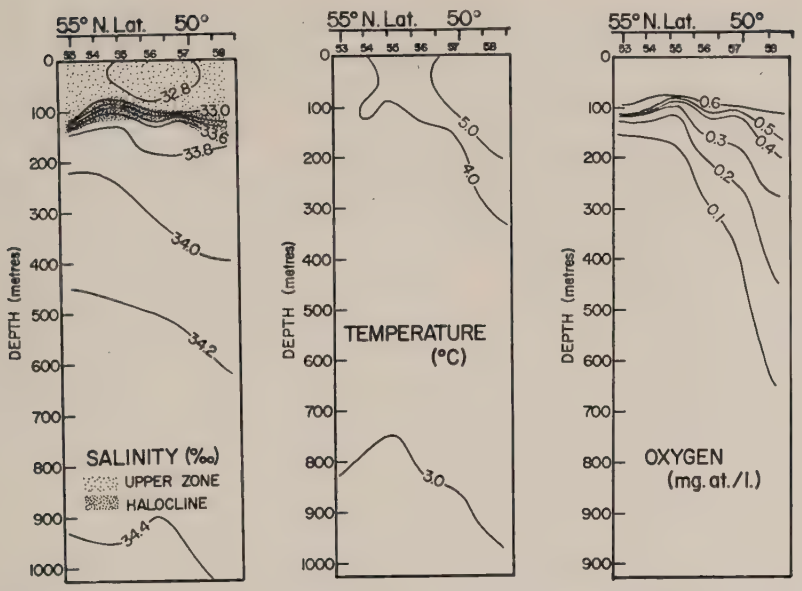


FIGURE 88. Vertical sections of salinity, temperature and dissolved oxygen along approx. long. 150°W., winter 1959.

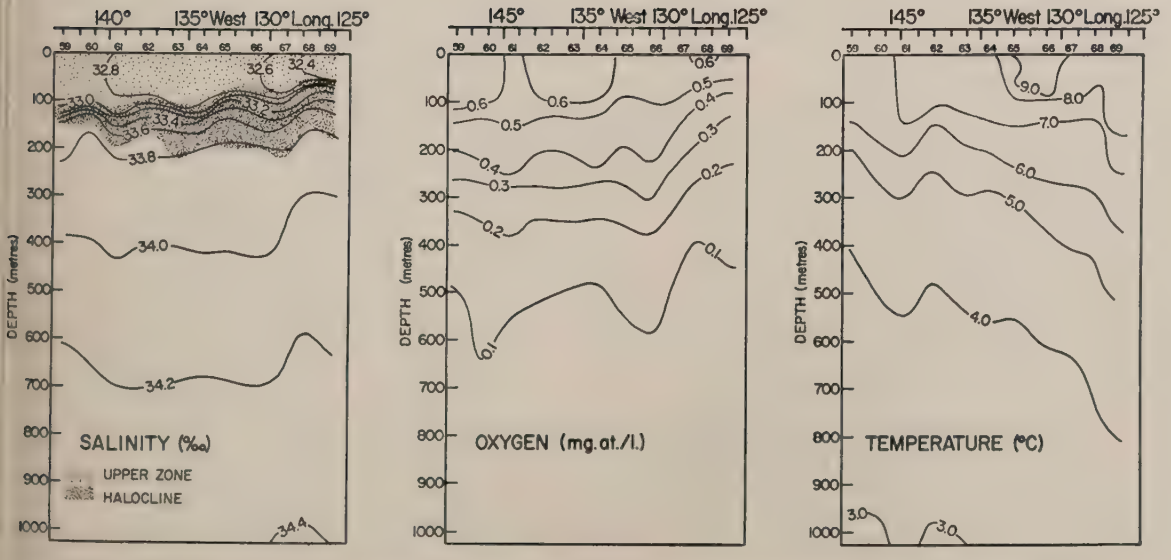


FIGURE 89. Vertical sections of salinity, temperature and dissolved oxygen along approx. lat. 47°N., winter 1959.

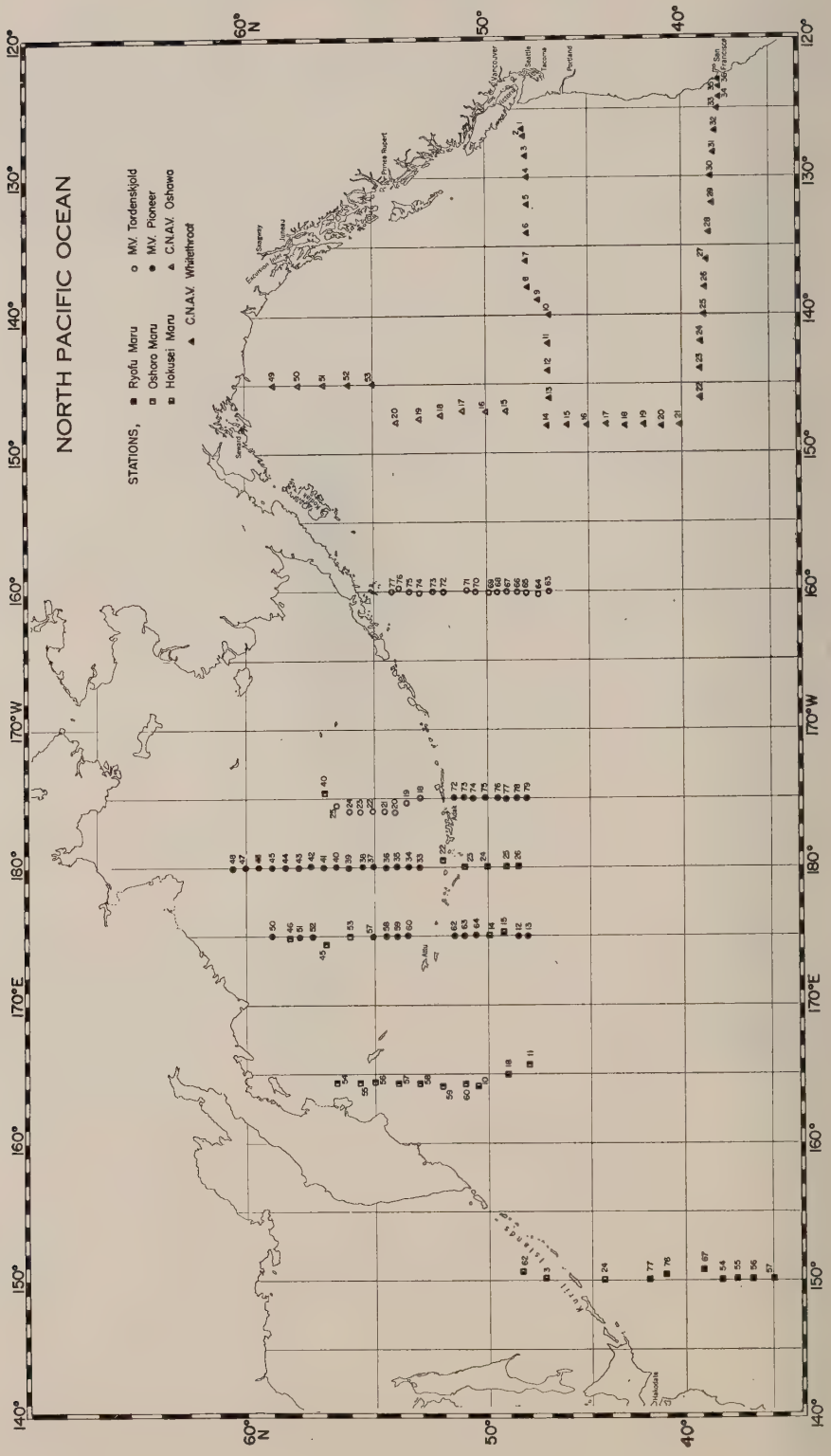


FIGURE 90. Locations of vertical sections, summer 1959.

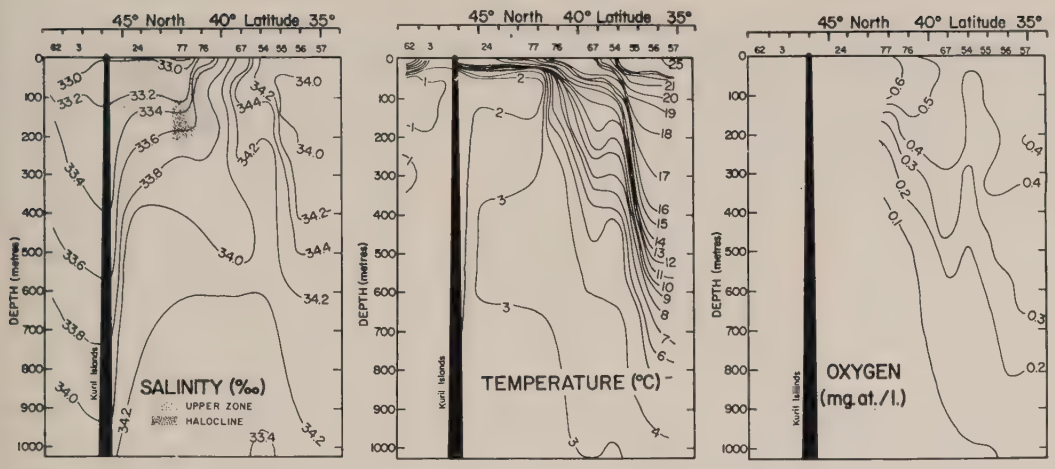


FIGURE 91. Vertical sections of salinity, temperature and dissolved oxygen along long. 150°E., summer 1959.

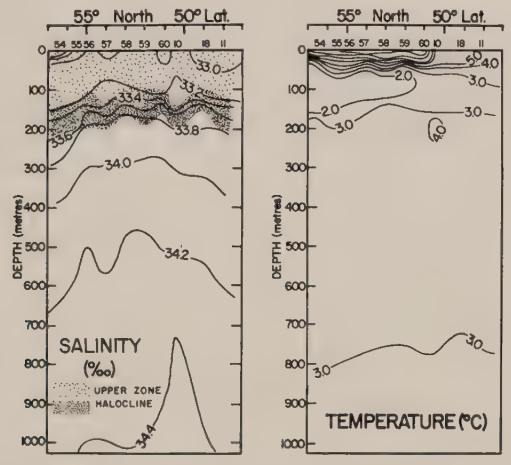


FIGURE 92. Vertical sections of salinity and temperature along approx. long. 165°E., summer 1959.

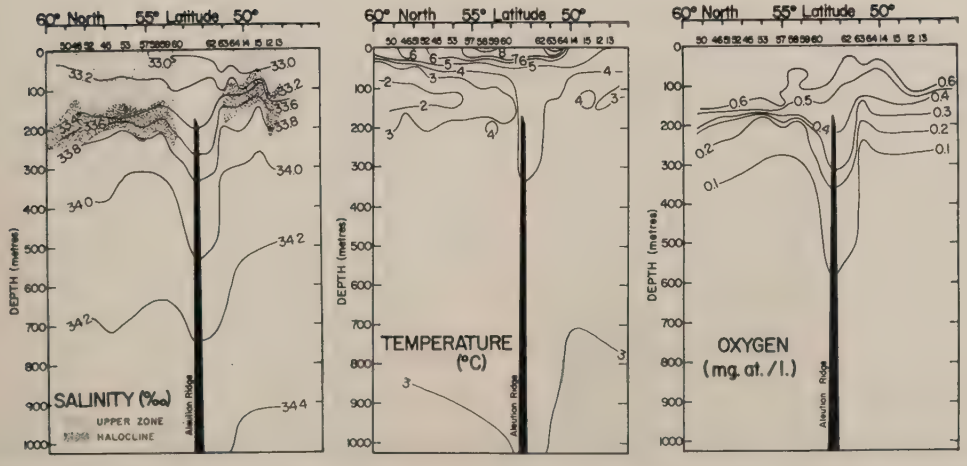


FIGURE 93. Vertical sections of salinity, temperature and dissolved oxygen along long. 175°E., summer 1959.

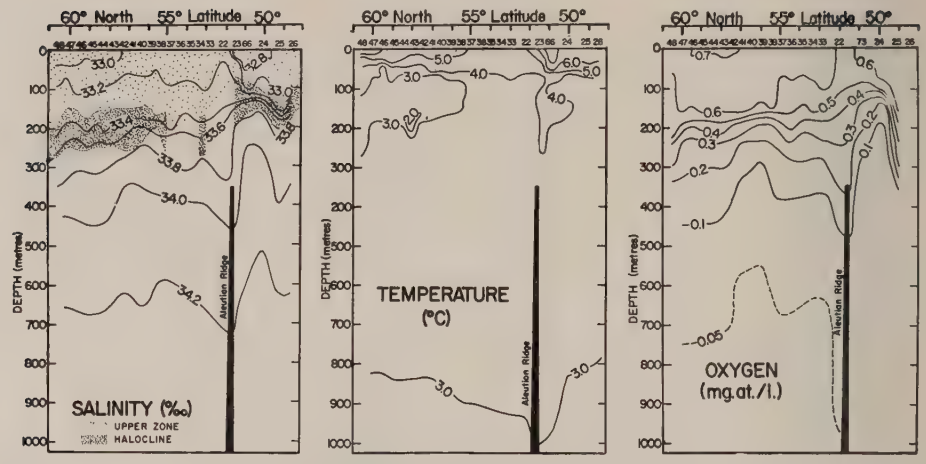


FIGURE 94. Vertical sections of salinity, temperature and dissolved oxygen along long. 180°, summer 1959.

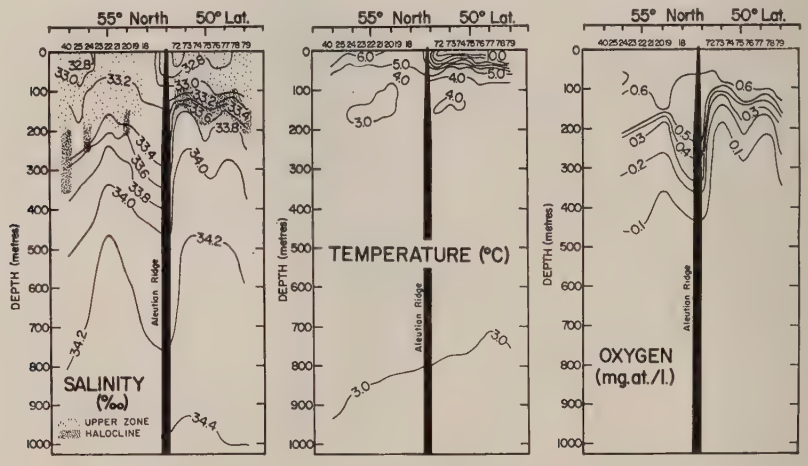


FIGURE 95. Vertical sections of salinity, temperature and dissolved oxygen along long. 175°W., summer 1959.

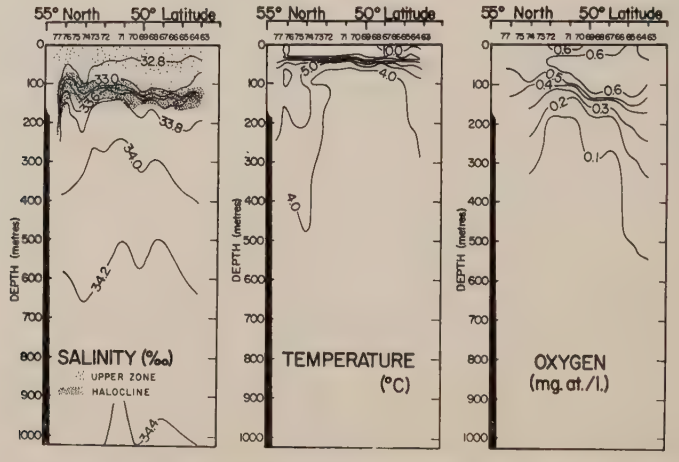


FIGURE 96. Vertical sections of salinity, temperature and dissolved oxygen along long. 160°W., summer 1959.

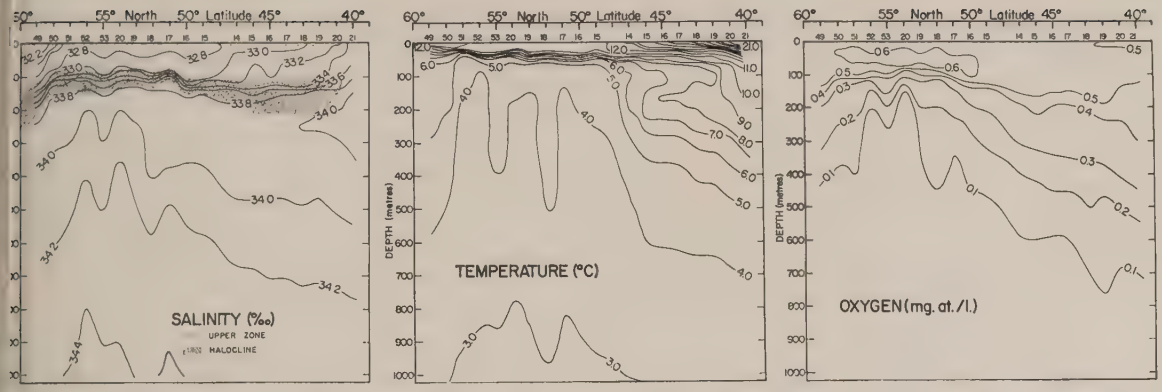


FIGURE 97. Vertical sections of salinity, temperature and dissolved oxygen along approx. long. 145°W., summer 1959.

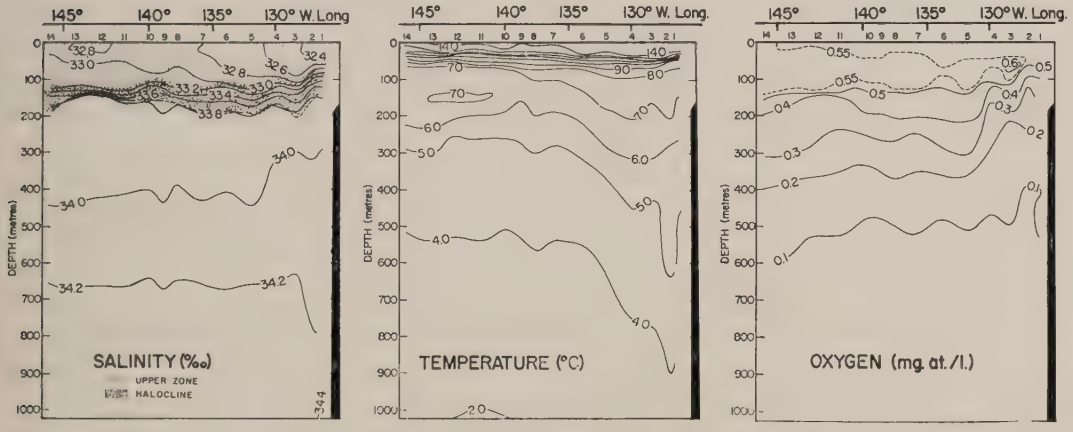


FIGURE 98. Vertical sections of salinity, temperature and dissolved oxygen along approx. lat. 48°N., summer 1959.

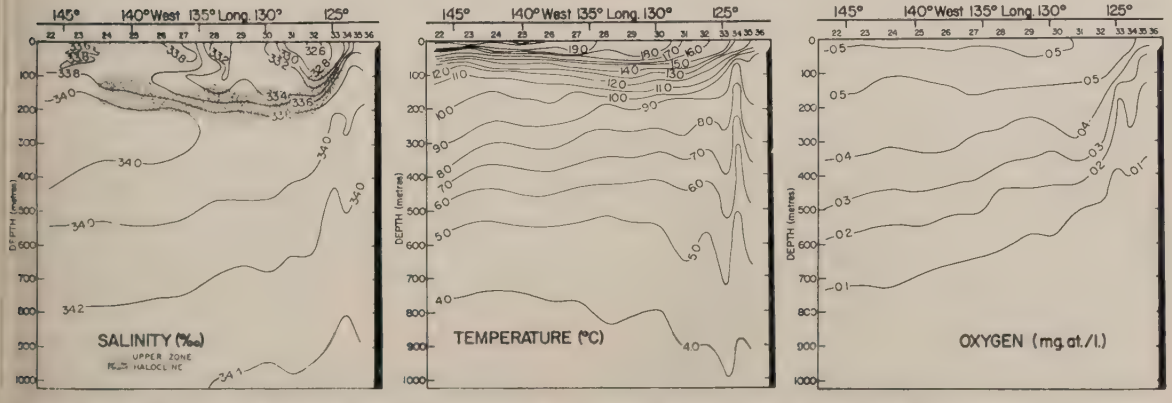


FIGURE 99. Vertical sections of salinity, temperature and dissolved oxygen along approx. lat. 38°N., summer 1959.

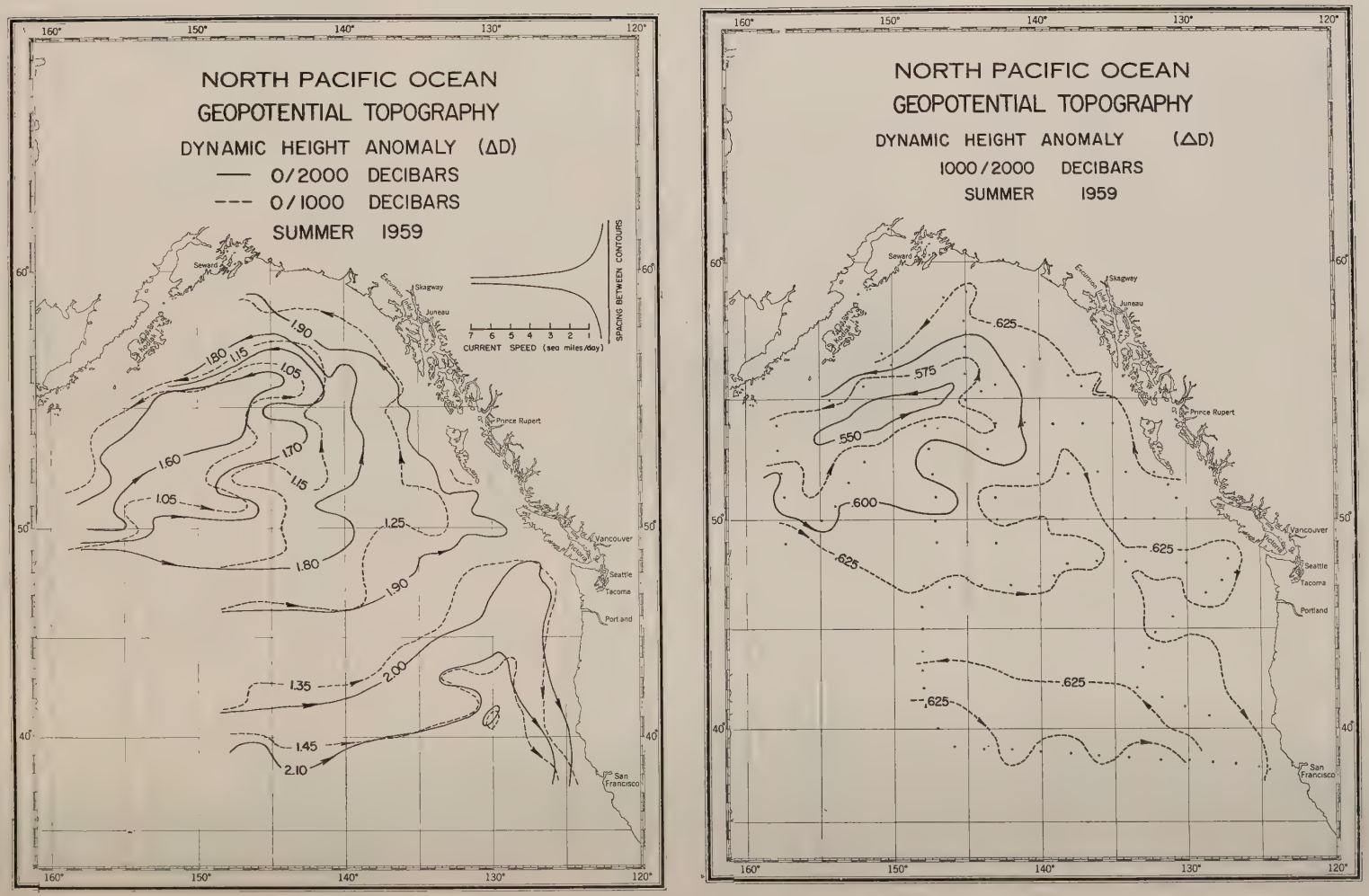


FIGURE 100. Geopotential topography, 0/1000, 0/2000 and 1000/2000 decibars, summer 1959.

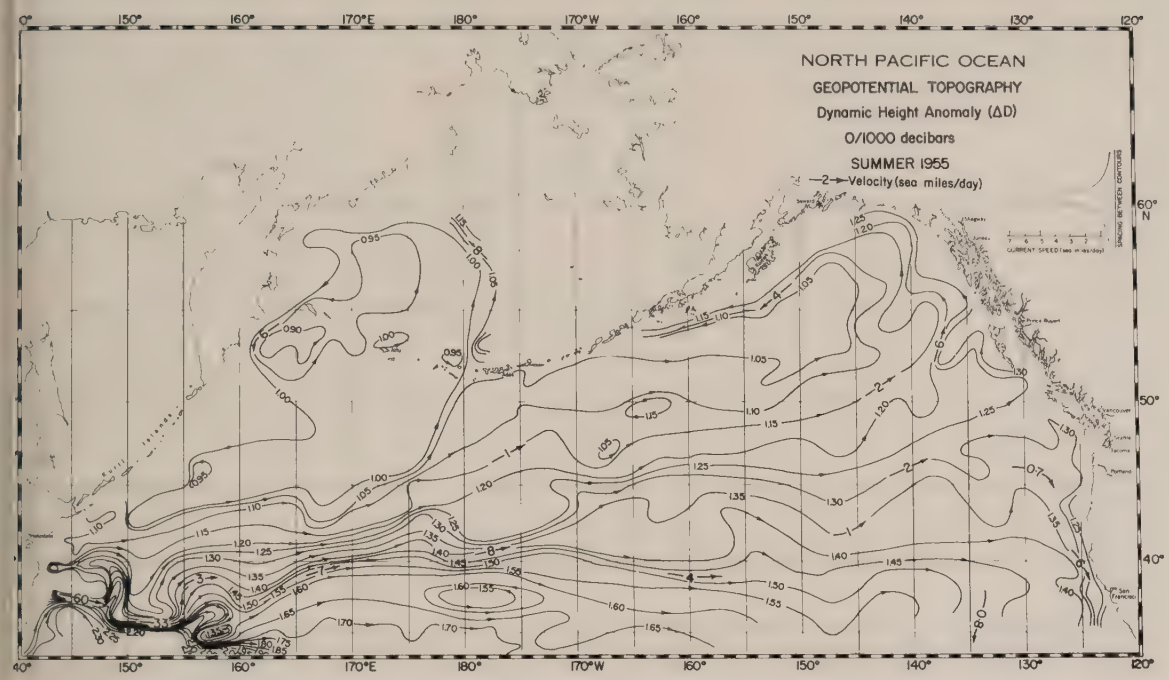


FIGURE 101. Geopotential topography, 0/1000 decibars, summer 1955.

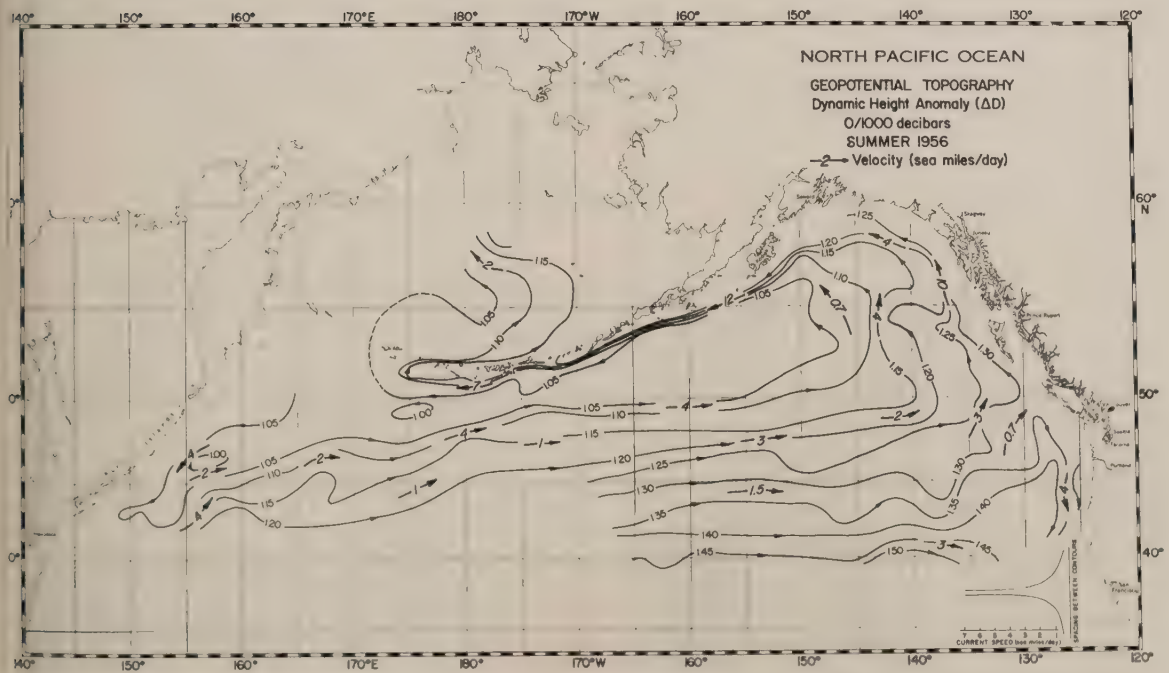


FIGURE 102. Geopotential topography, 0/1000 decibars, summer 1956.

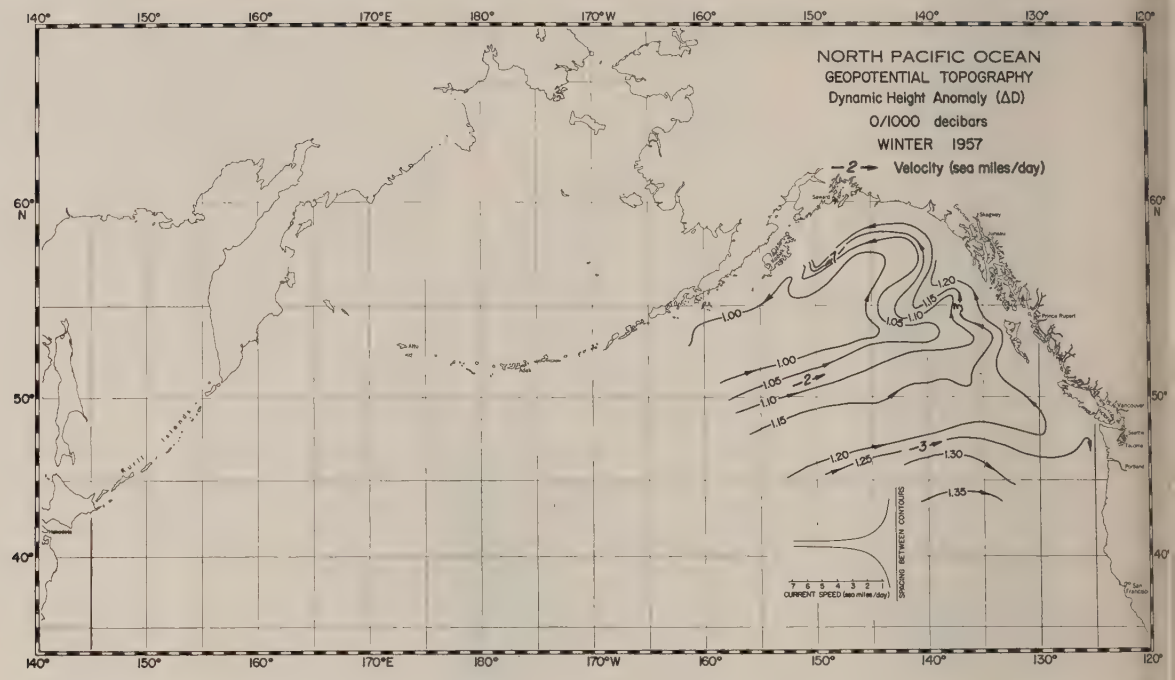


FIGURE 103. Geopotential topography, 0/1000 decibars, winter 1957.

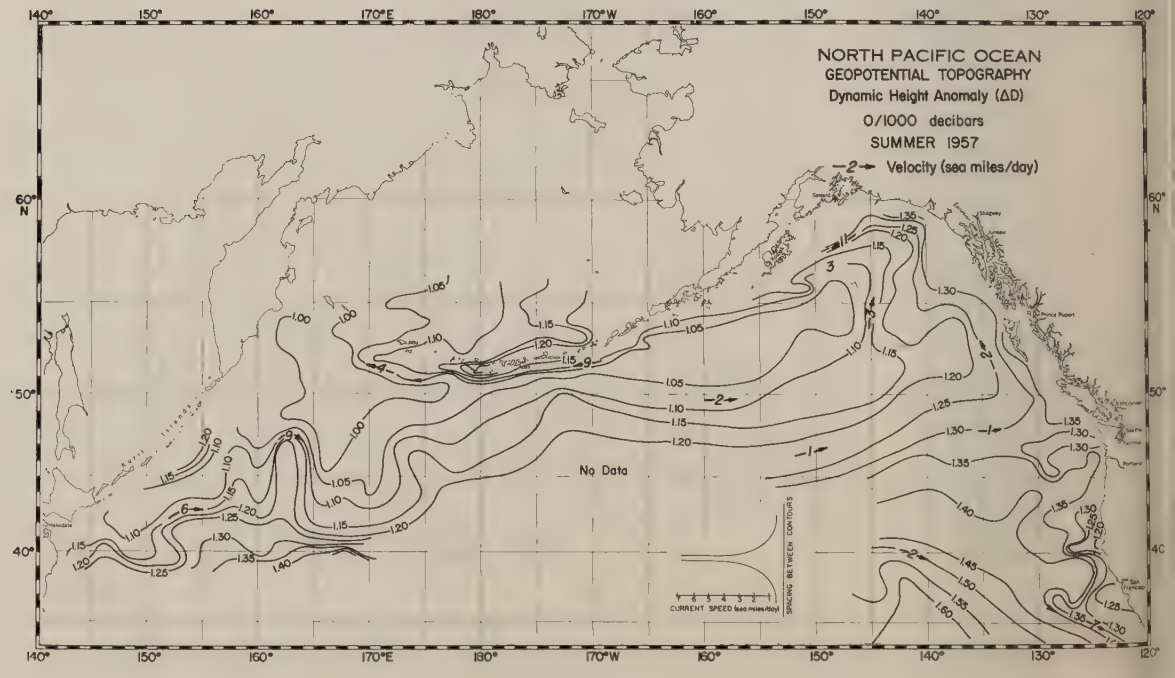


FIGURE 104. Geopotential topography, 0/1000 decibars, summer 1957.

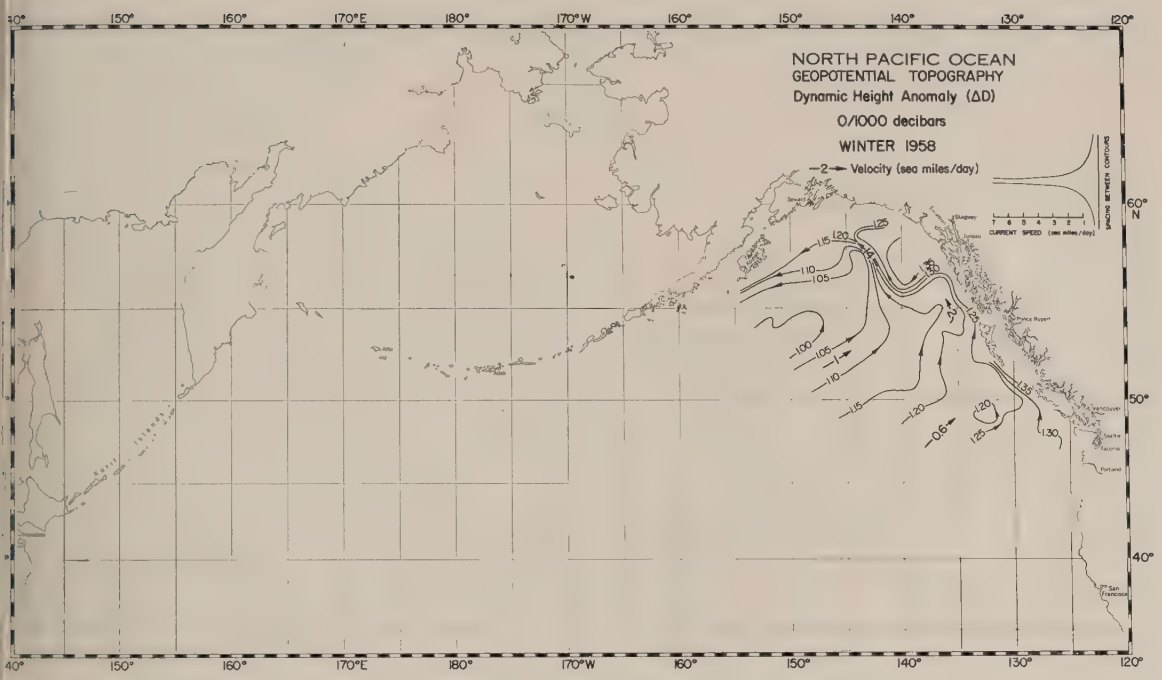


FIGURE 105. Geopotential topography, 0/1000 decibars, winter 1958.

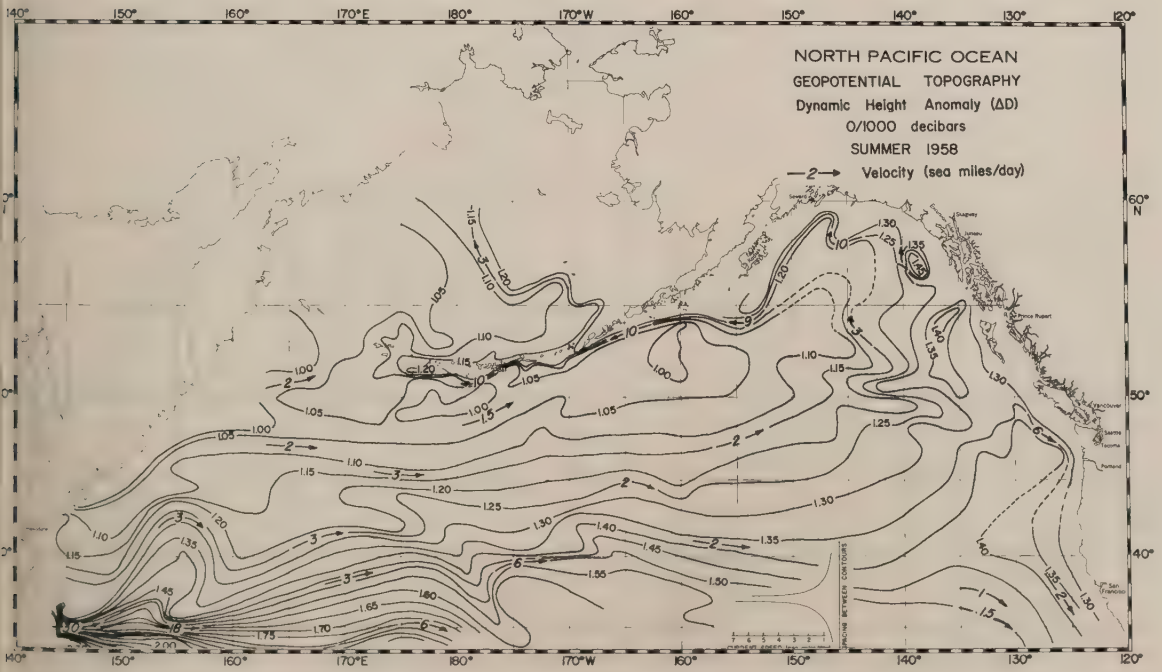


FIGURE 106. Geopotential topography, 0/1000 decibars, summer 1958.

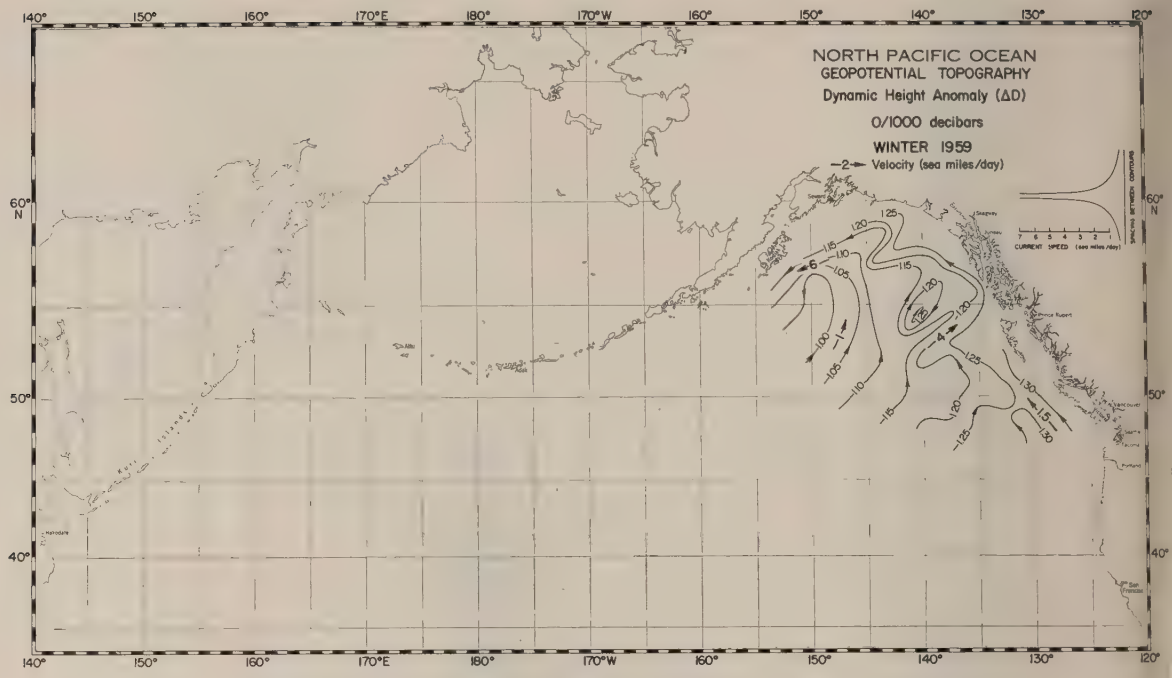


FIGURE 107. Geopotential topography, 0/1000 decibars, winter 1959.

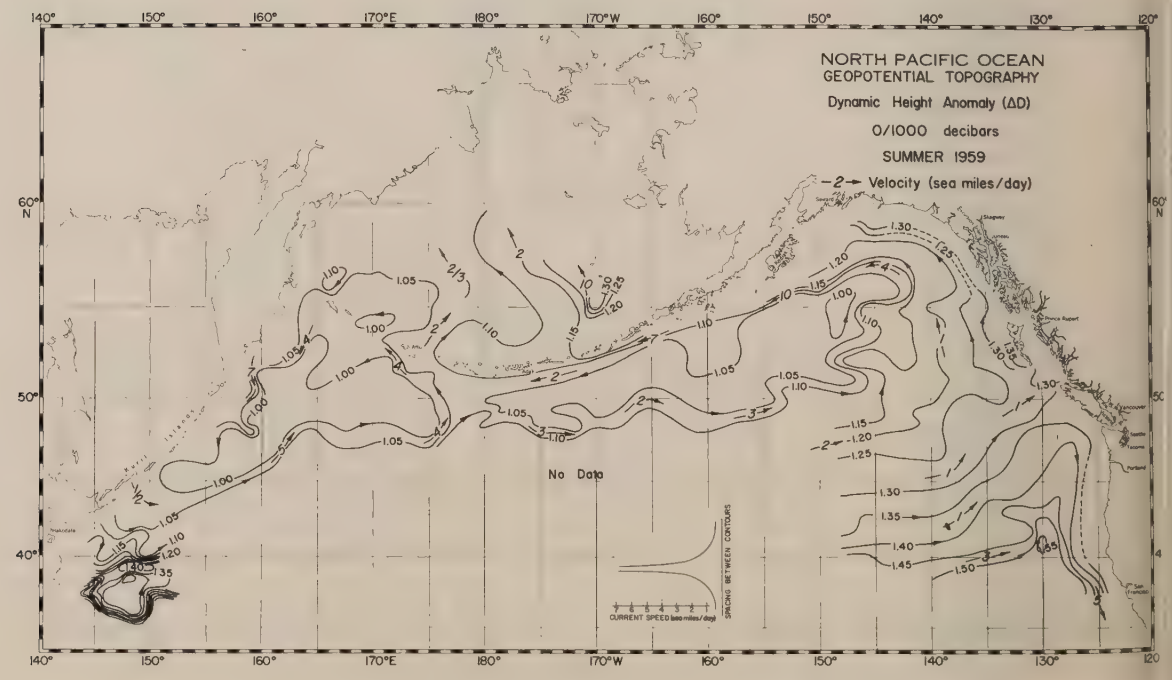


FIGURE 108. Geopotential topography, 0/1000 decibars, summer 1959.

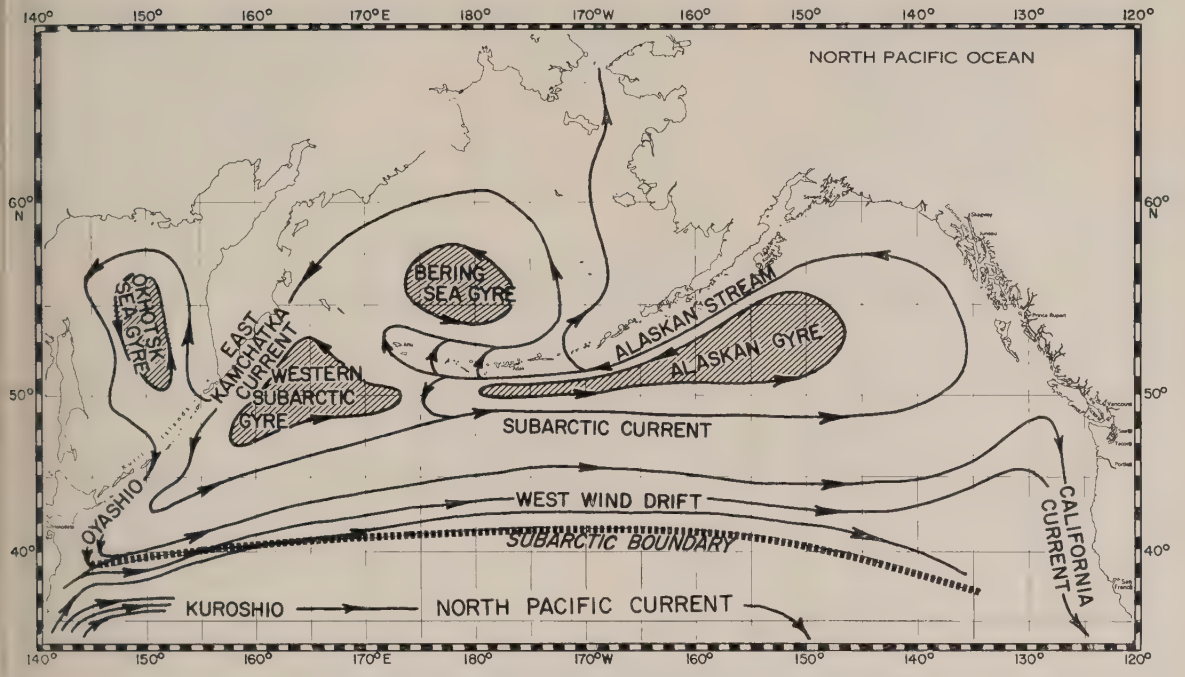


FIGURE 109. Schematic diagram of surface circulation relative to 1000 decibars.

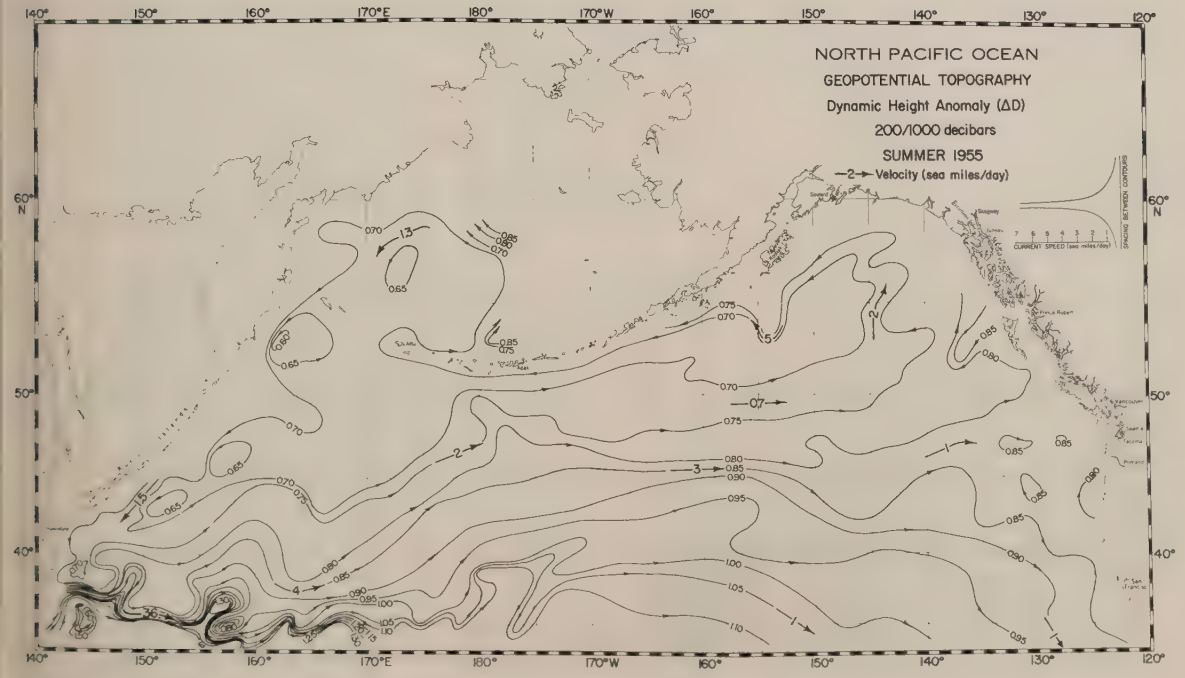


FIGURE 110. Geopotential topography, 200/1000 decibars, summer 1955.

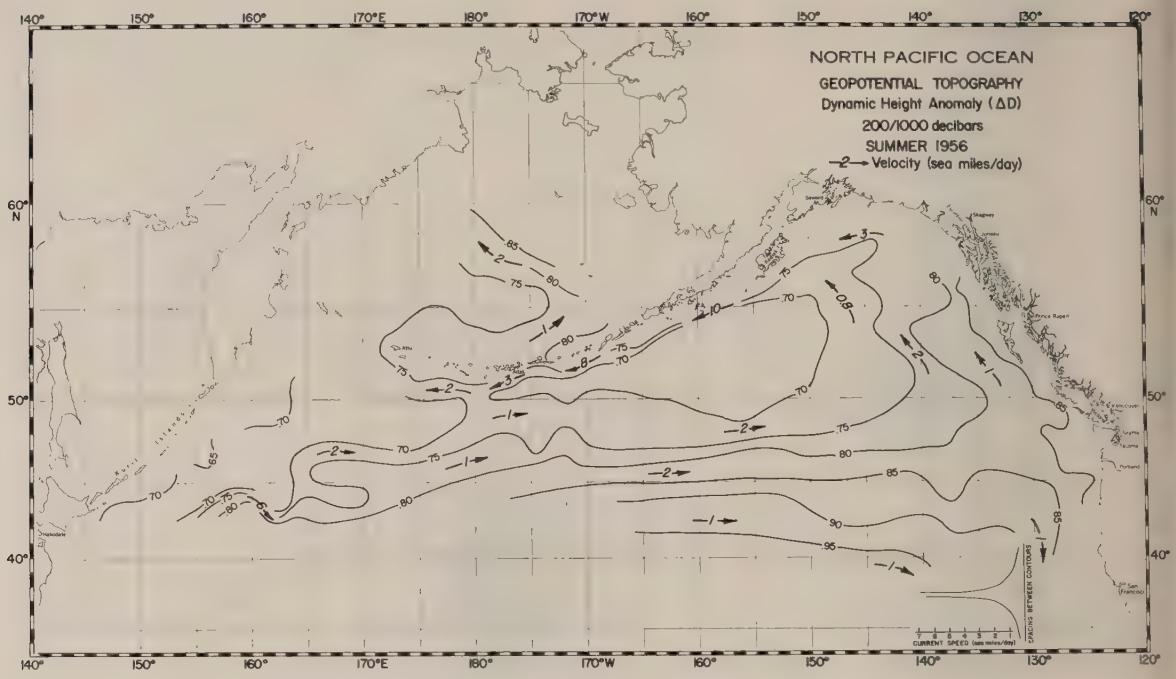


FIGURE 111. Geopotential topography, 200/1000 decibars, summer 1956.

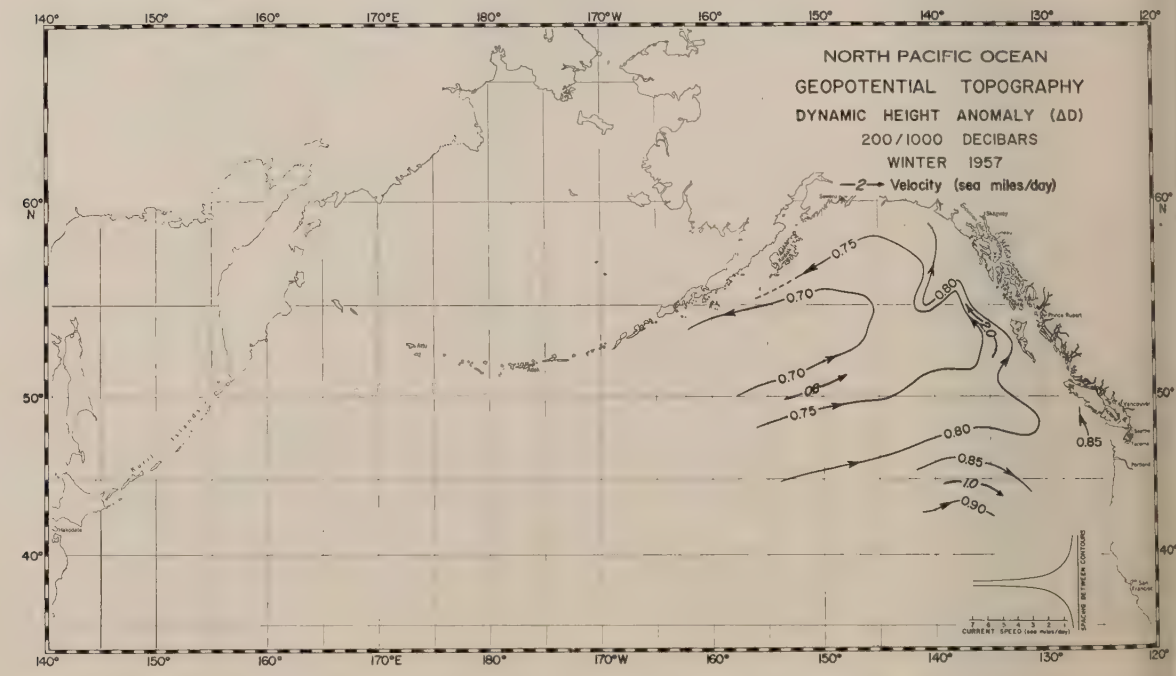


FIGURE 112. Geopotential topography, 200/1000 decibars, winter 1957.

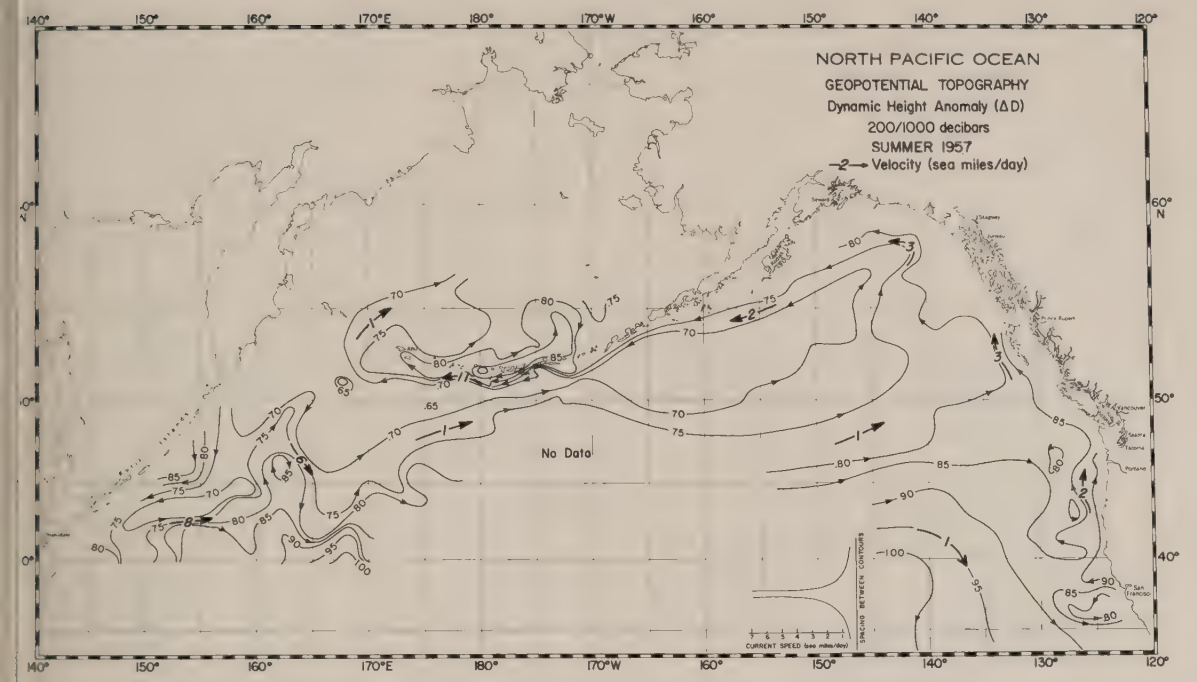


FIGURE 113. Geopotential topography, 200/1000 decibars, summer 1957.

FIGURE 114. Geopotential topography, 200/1000 decibars, winter 1958.

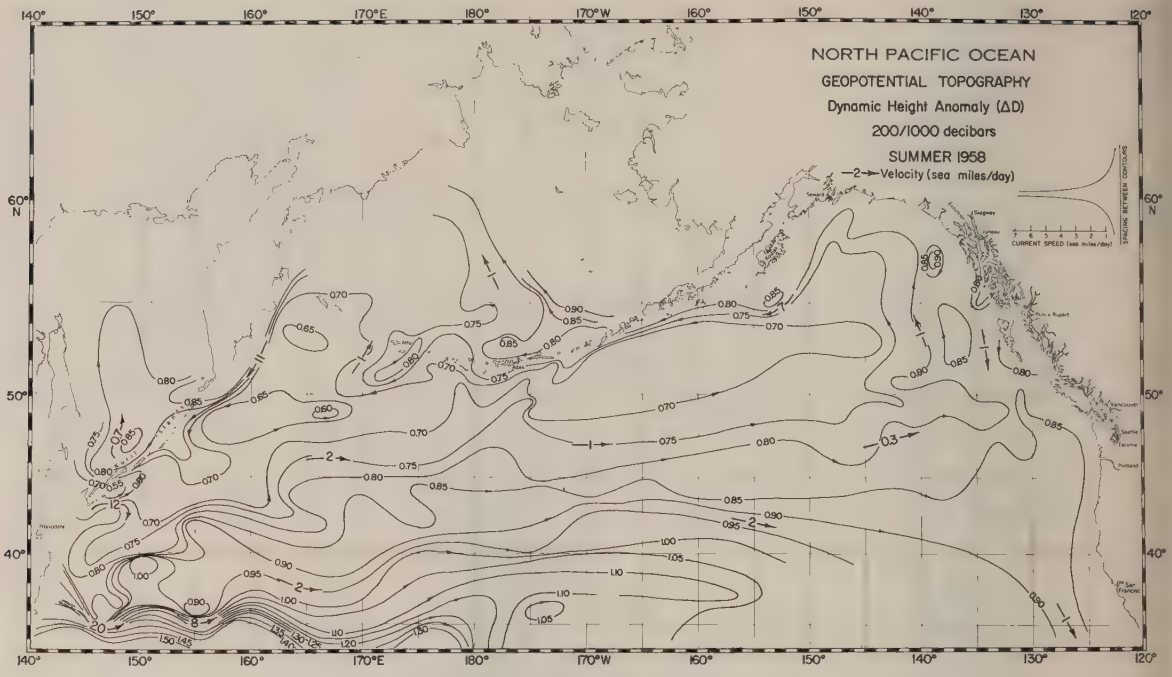


FIGURE 115. Geopotential topography, 200/1000 decibars, summer 1958.

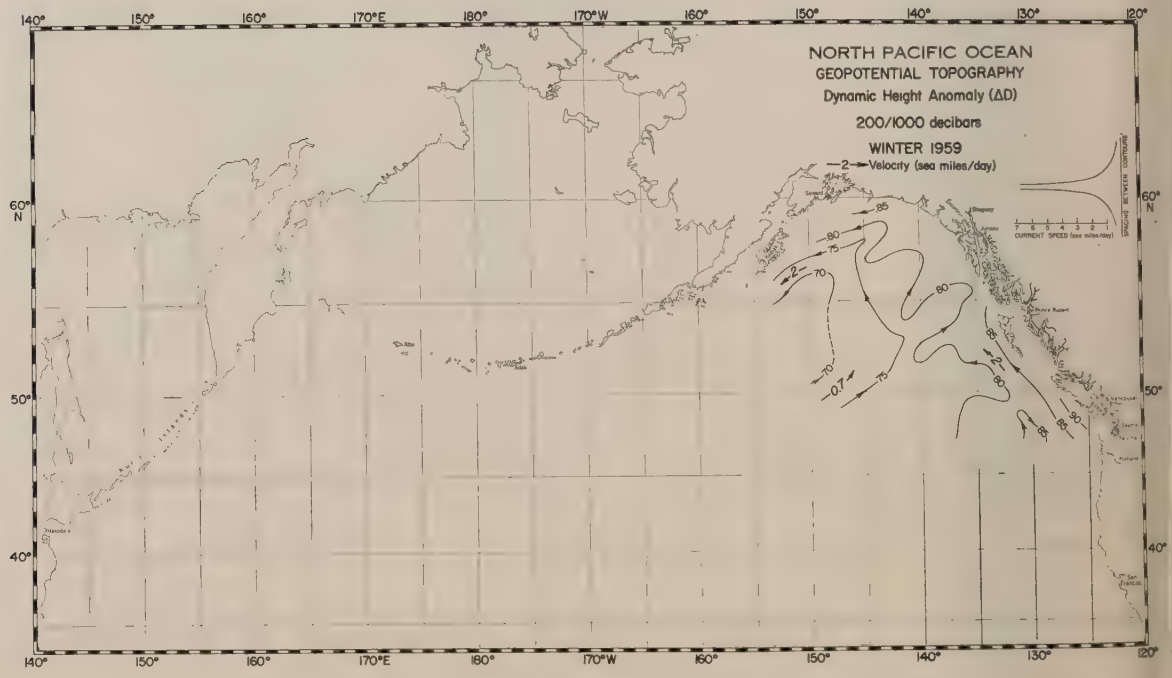


FIGURE 116. Geopotential topography, 200/1000 decibars, winter 1959.

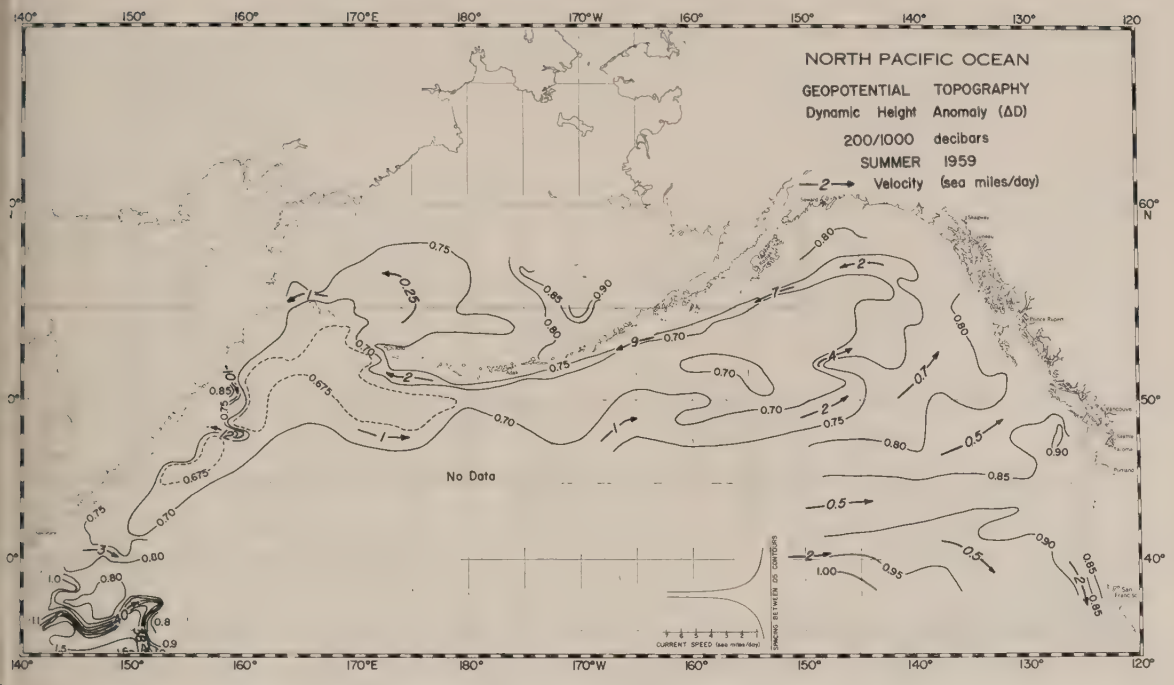


FIGURE 117. Geopotential topography, 200/1000 decibars, summer 1959.

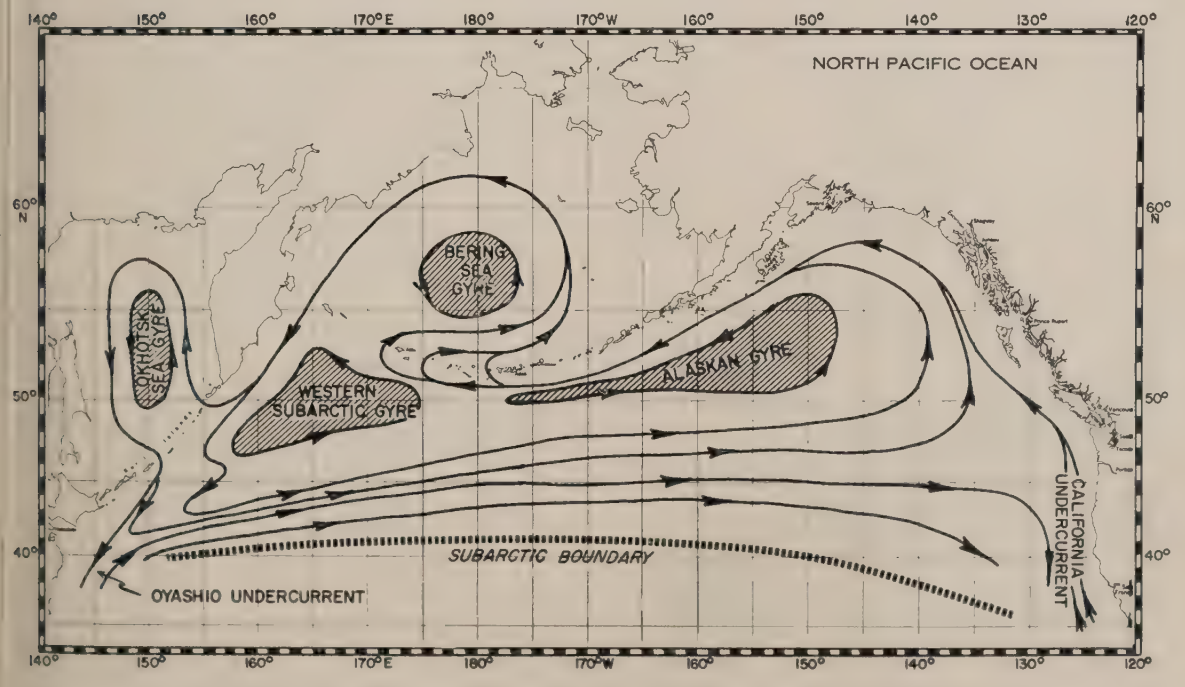


FIGURE 118. Schematic diagram of circulation at 200 decibars relative to 1000 decibars.

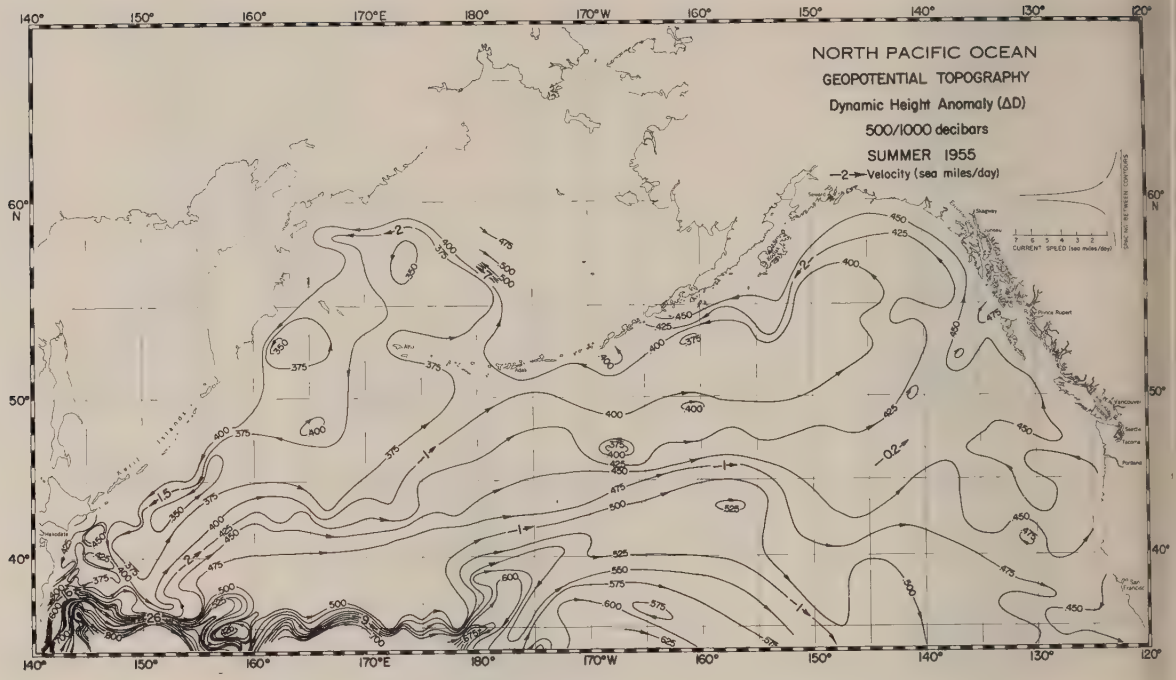


FIGURE 119. Geopotential topography, 500/1000 decibars, summer 1955.

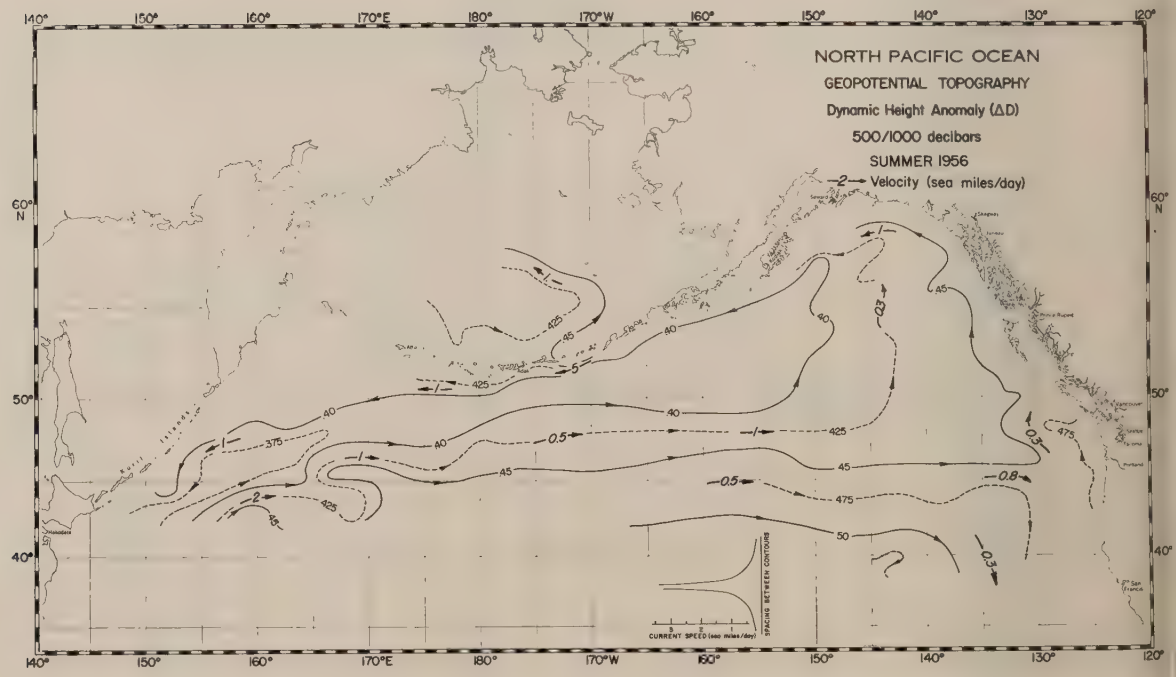


FIGURE 120. Geopotential topography, 500/1000 decibars, summer 1956.

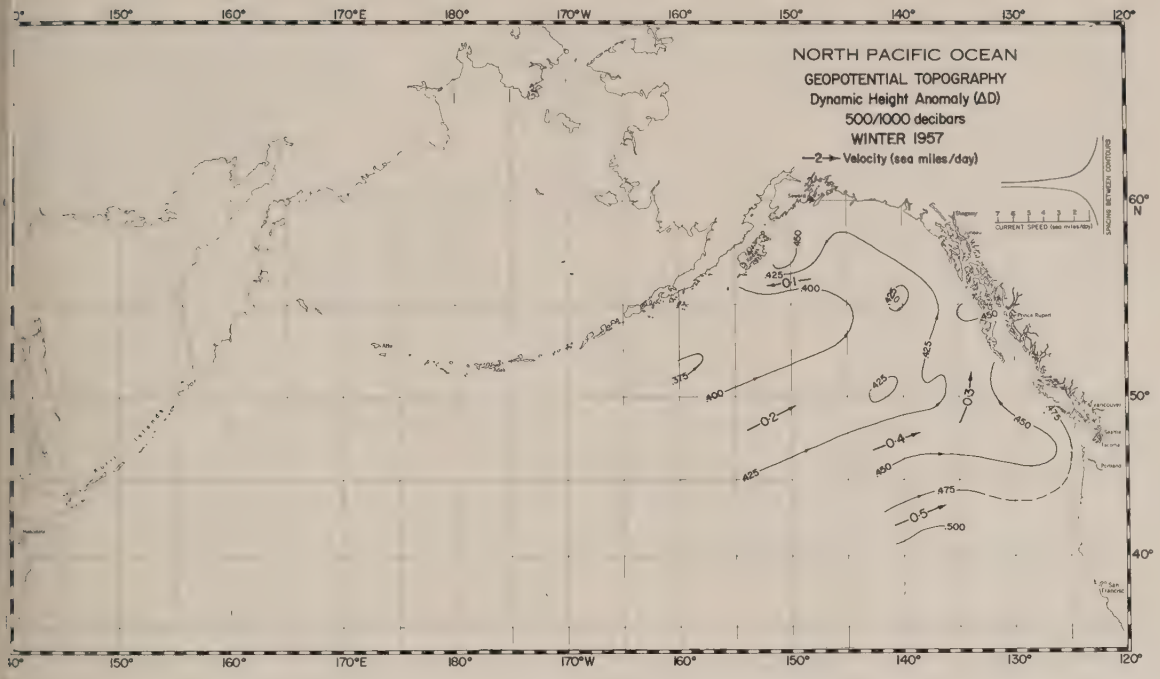


FIGURE 121. Geopotential topography, 500/1000 decibars, winter 1957.

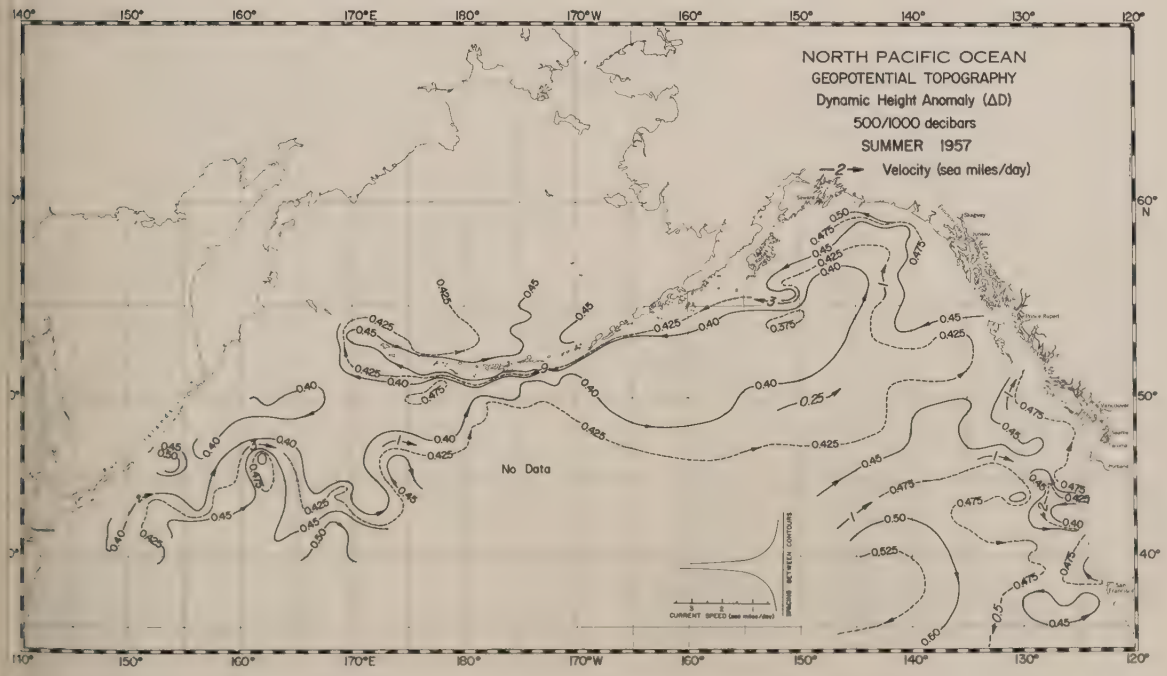


FIGURE 122. Geopotential topography, 500/1000 decibars, summer 1957.

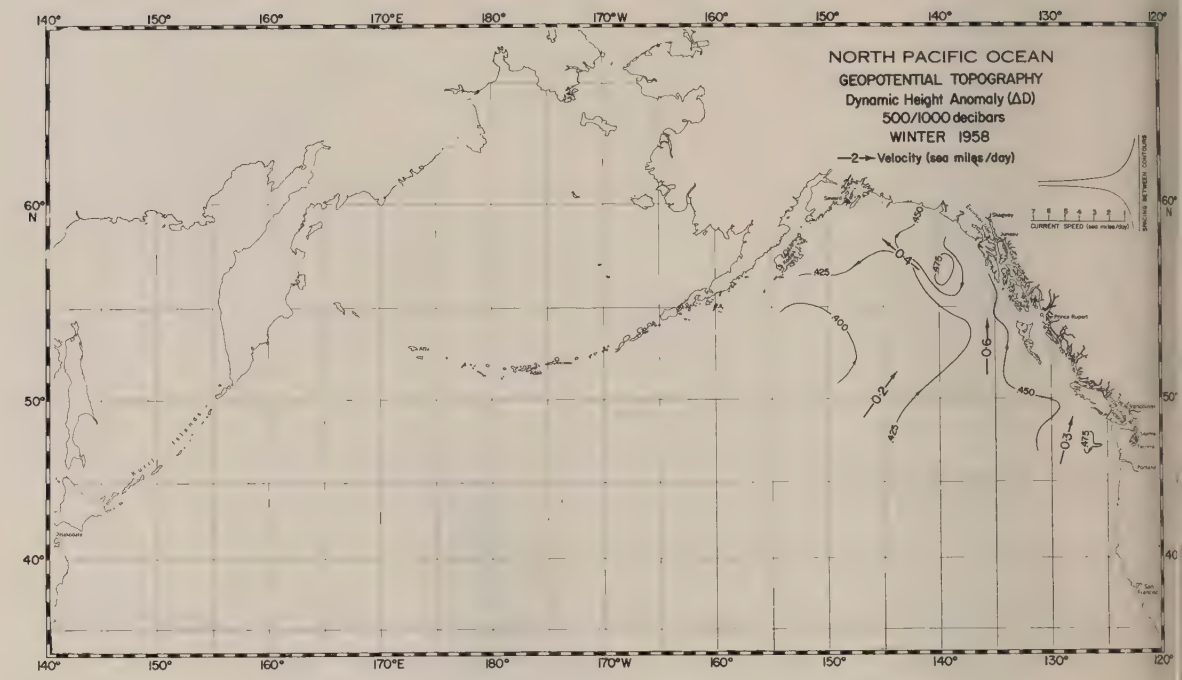


FIGURE 123. Geopotential topography, 500/1000 decibars, winter 1958.

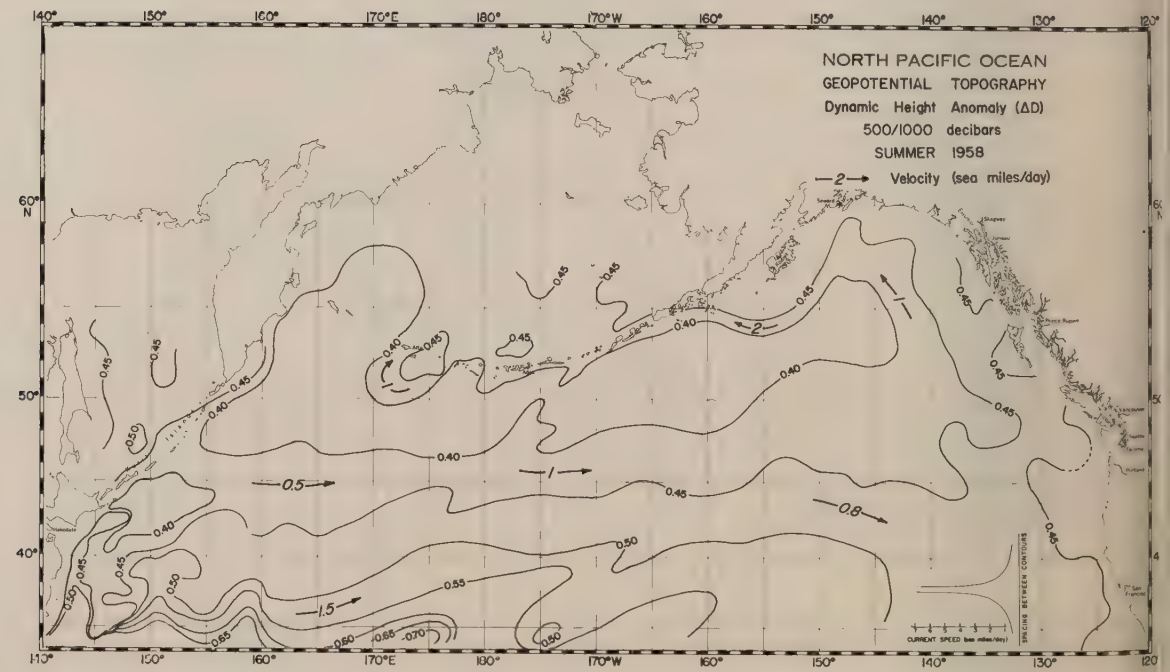


FIGURE 124. Geopotential topography, 500/1000 decibars, summer 1958.

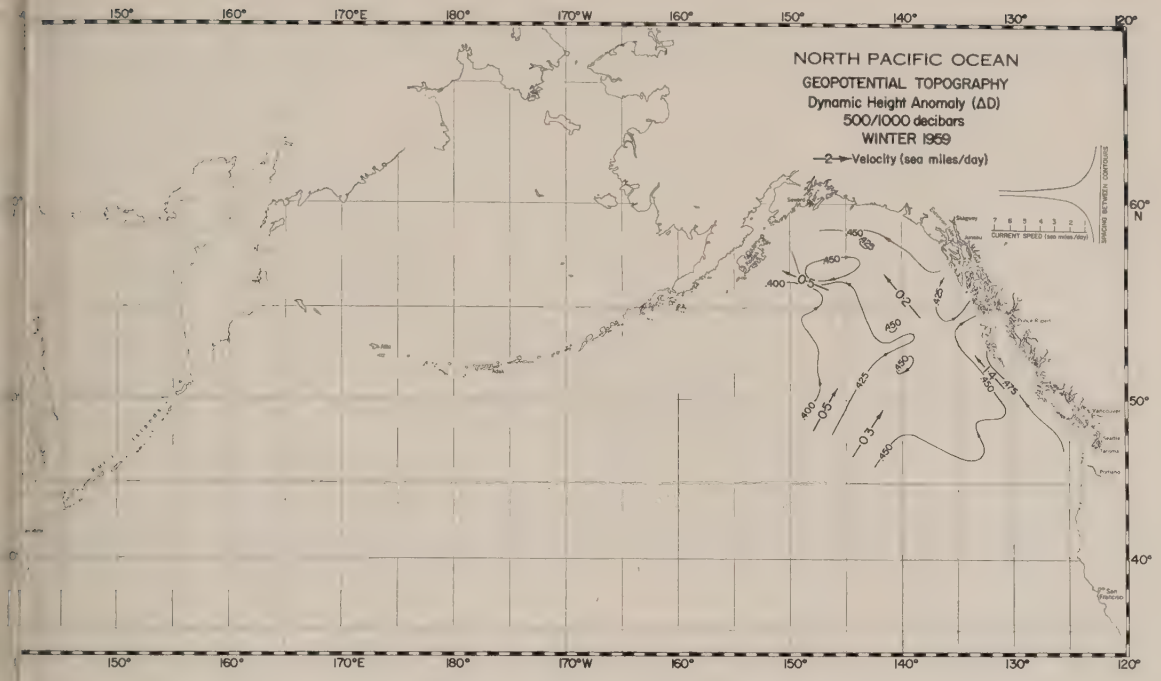


FIGURE 125. Geopotential topography, 500/1000 decibars, winter 1959.

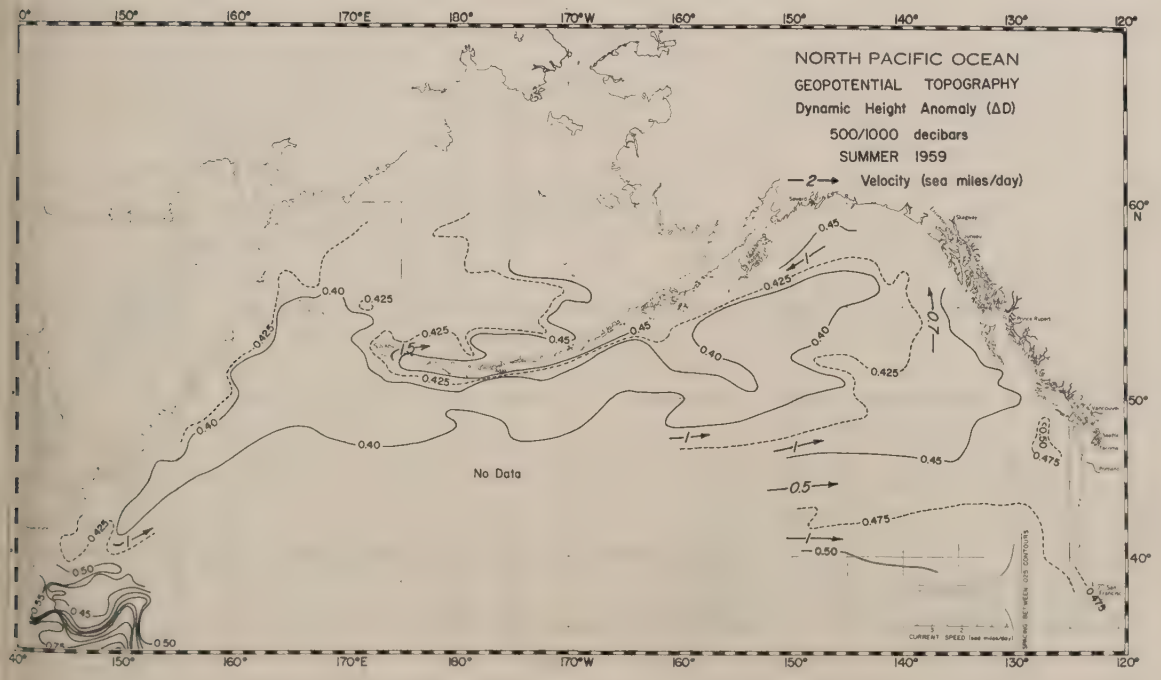


FIGURE 126. Geopotential topography, 500/1000 decibars, summer 1959.

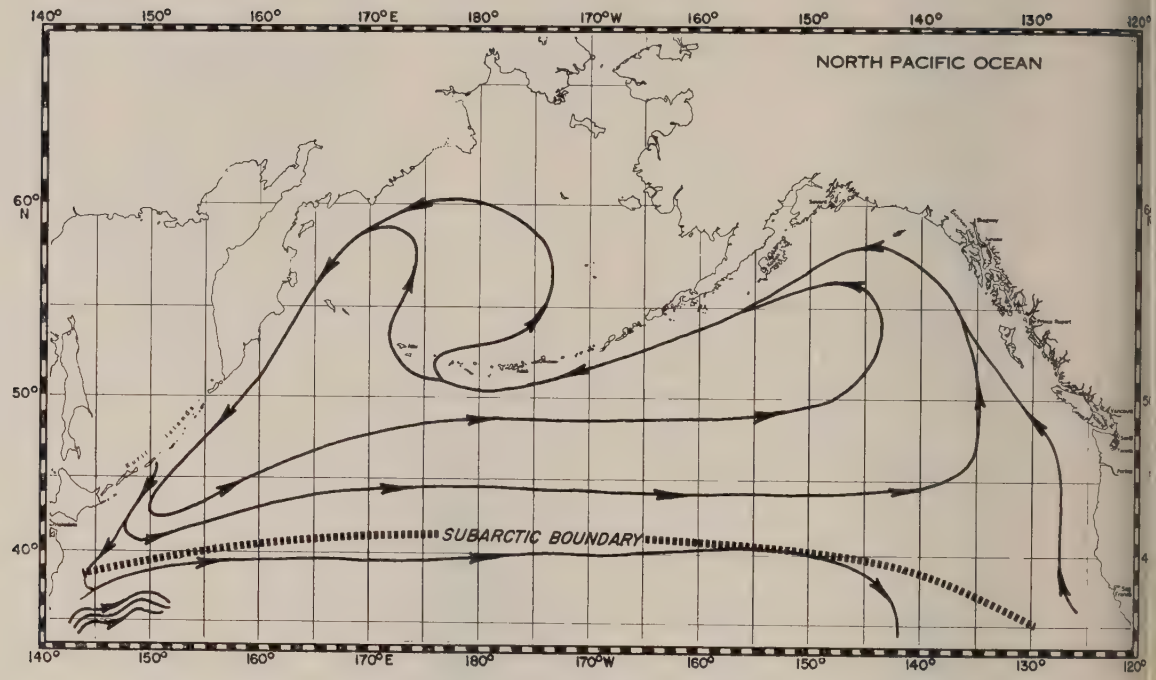


FIGURE 127. Schematic diagram of circulation at 500 decibars relative to 1000 decibars.

FIGURE 128. Geopotential topography, 0/200 decibars, summer 1955.

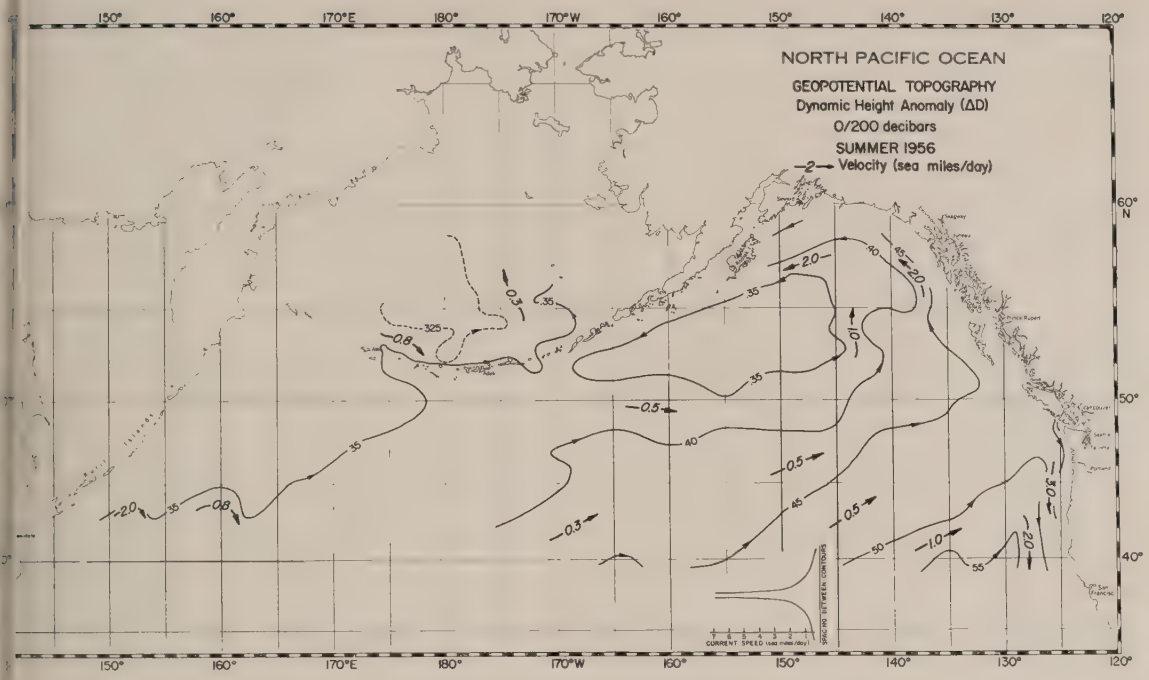


FIGURE 129. Geopotential topography, 0/200 decibars, summer 1956.

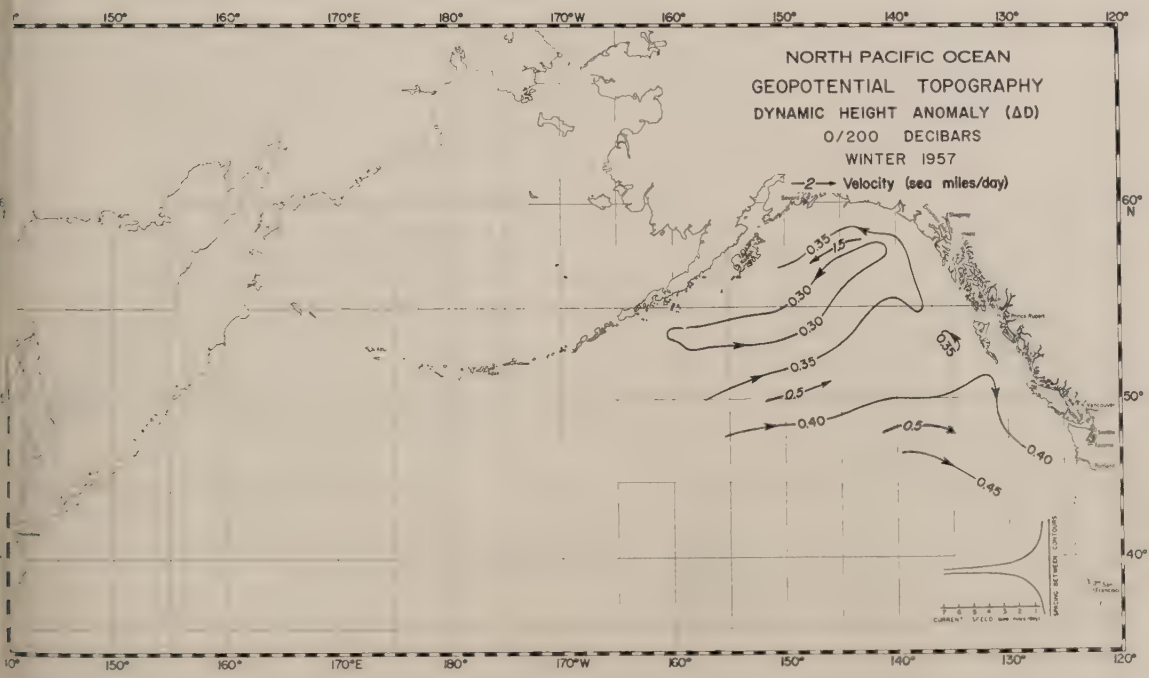


FIGURE 130. Geopotential topography, 0/200 decibars, winter 1957.

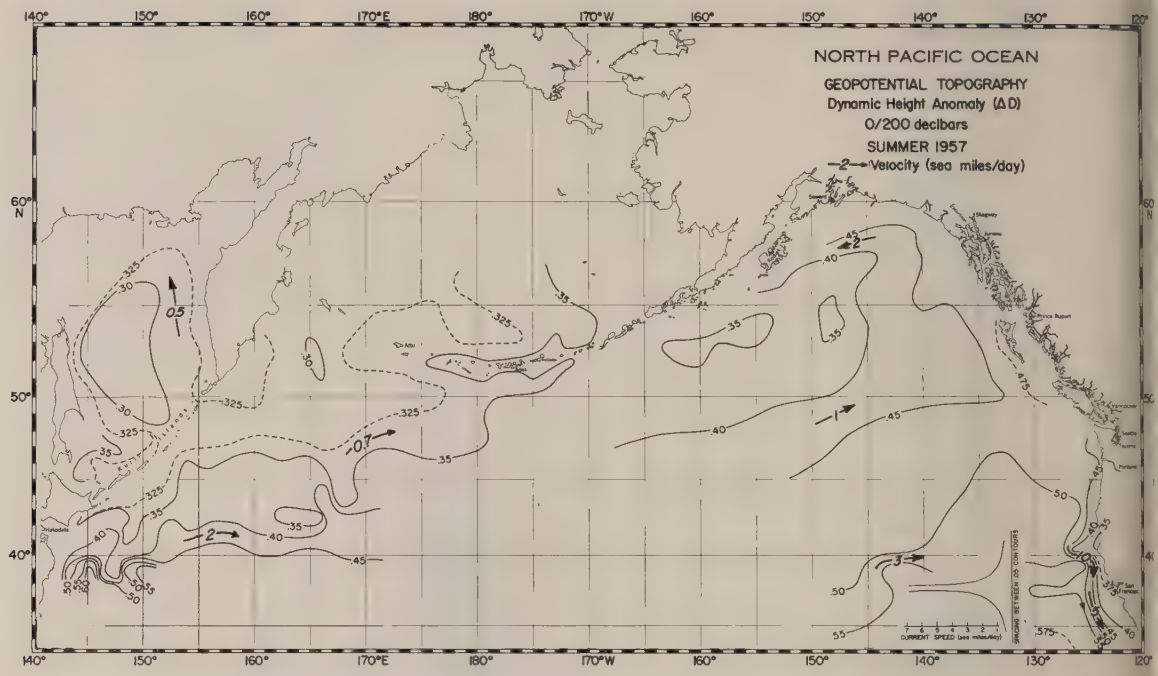


FIGURE 131. Geopotential topography, 0/200 decibars, summer 1957.

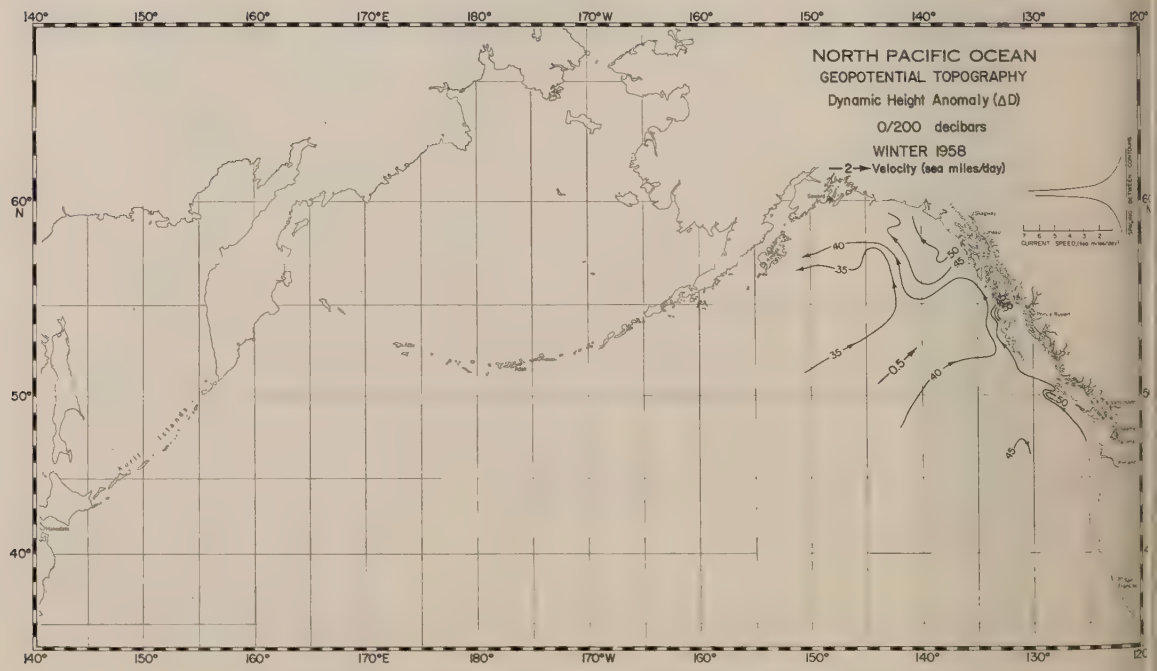


FIGURE 132. Geopotential topography, 0/200 decibars, winter 1958.

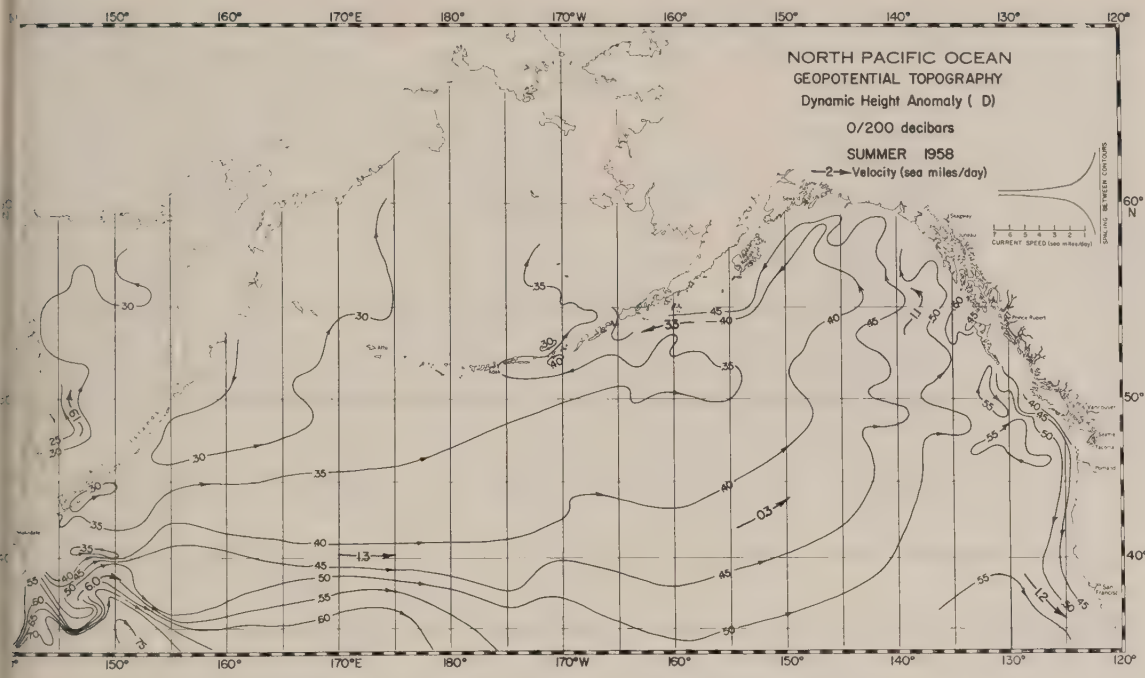


FIGURE 133. Geopotential topography, 0/200 decibars, summer 1958.

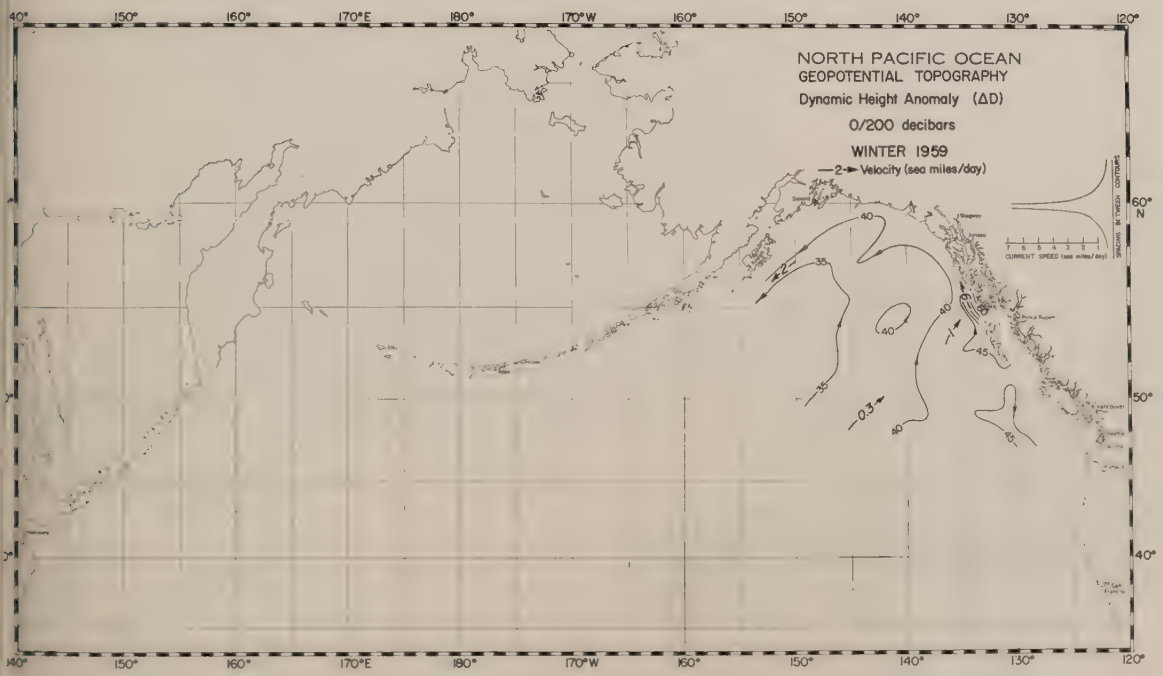


FIGURE 134. Geopotential topography, 0/200 decibars, winter 1959.

FIGURE 135. Geopotential topography, 0/200 decibars, summer 1959.

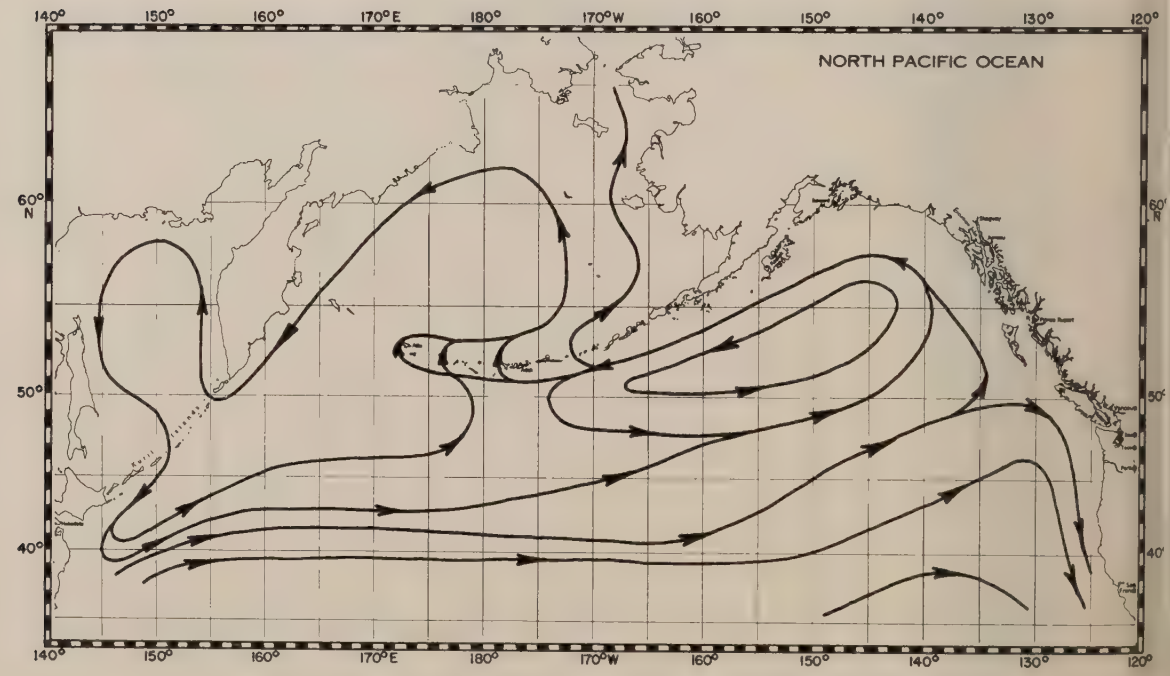


FIGURE 136. Schematic diagram of surface circulation relative to 200 decibars.

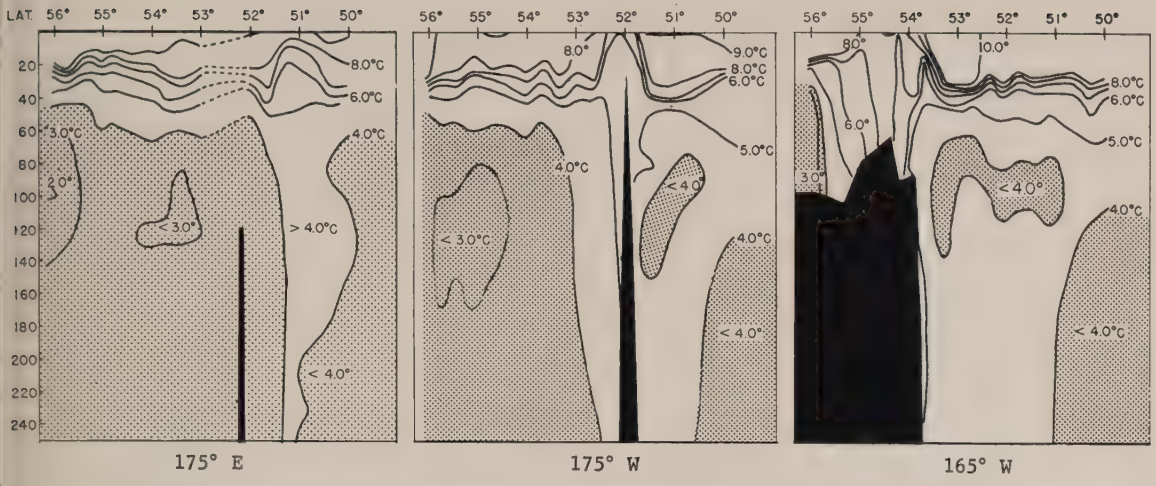


FIGURE 137a. Temperature sections across Aleutian Chain at long. 175°E., 175°W. and 165°W., July 1957. (Aleutian Chain shown in black.)

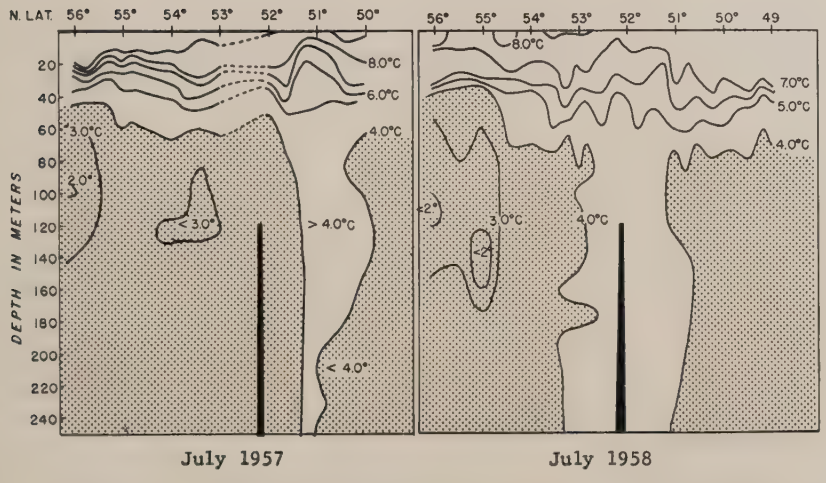
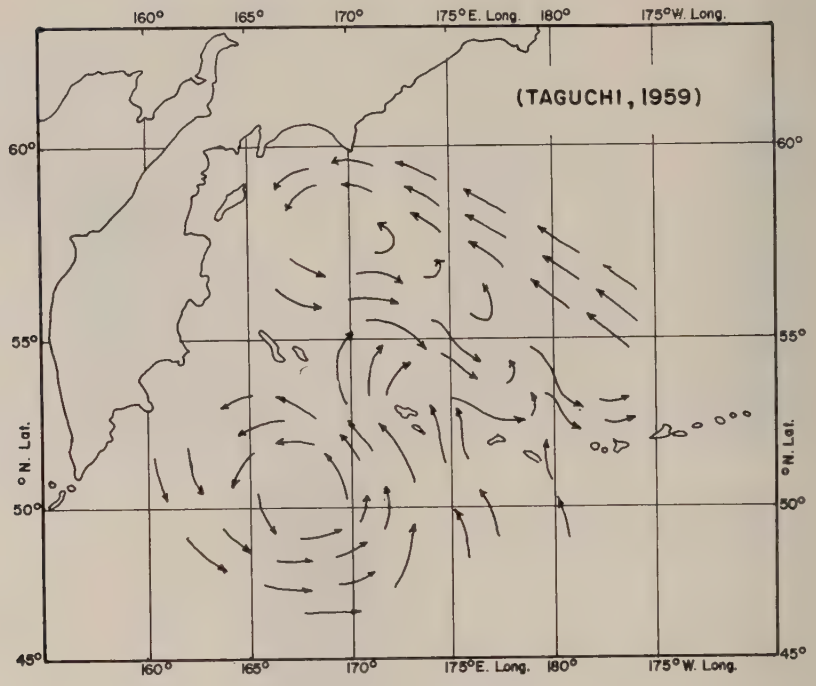


FIGURE 137b. Temperature sections across Aleutian Chain at long. 175°E., July 1957 and 1958. (Aleutian Chain shown in black.)



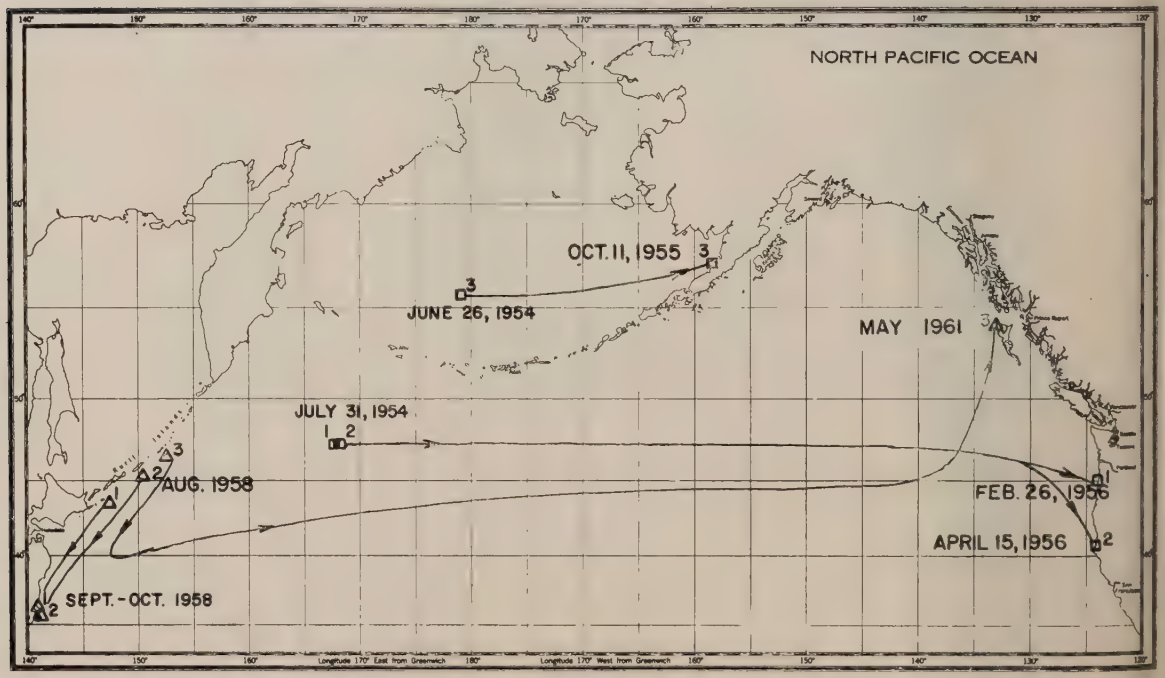


FIGURE 138. Drift bottle releases in western Subarctic.

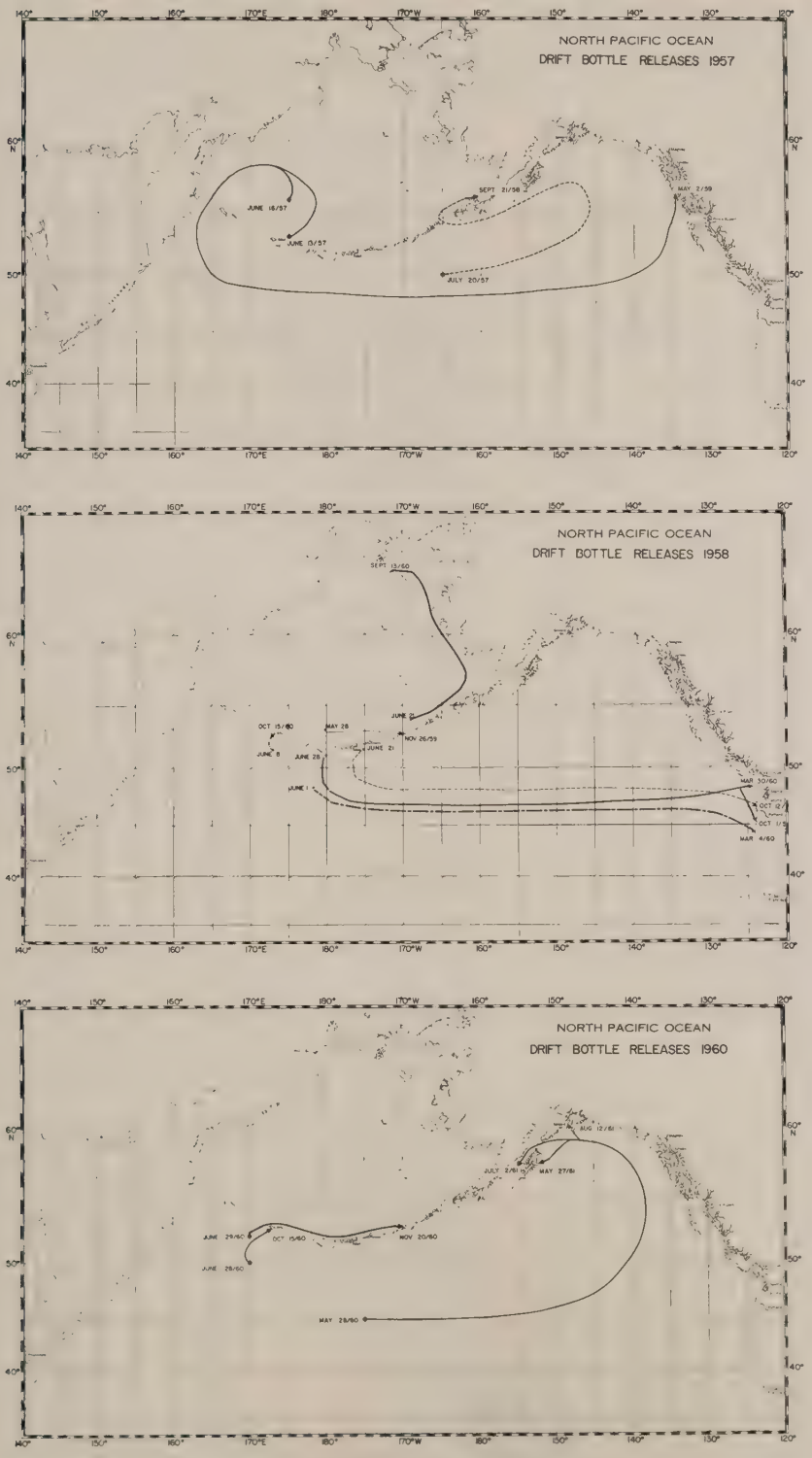
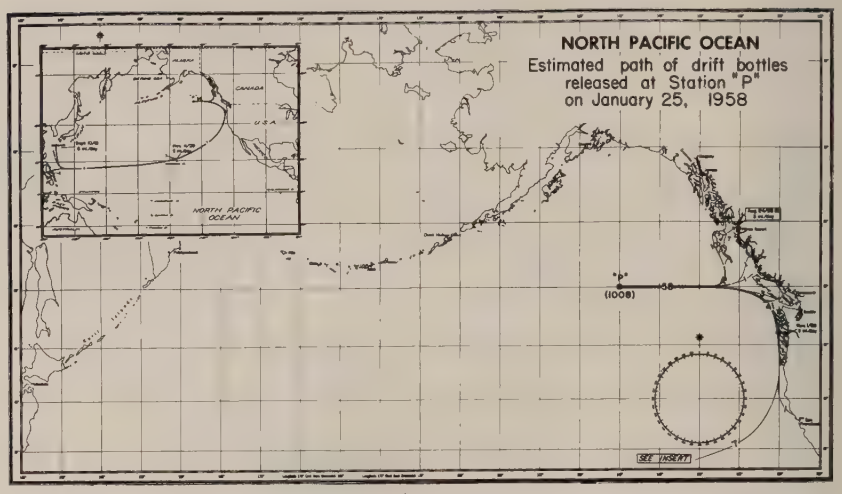
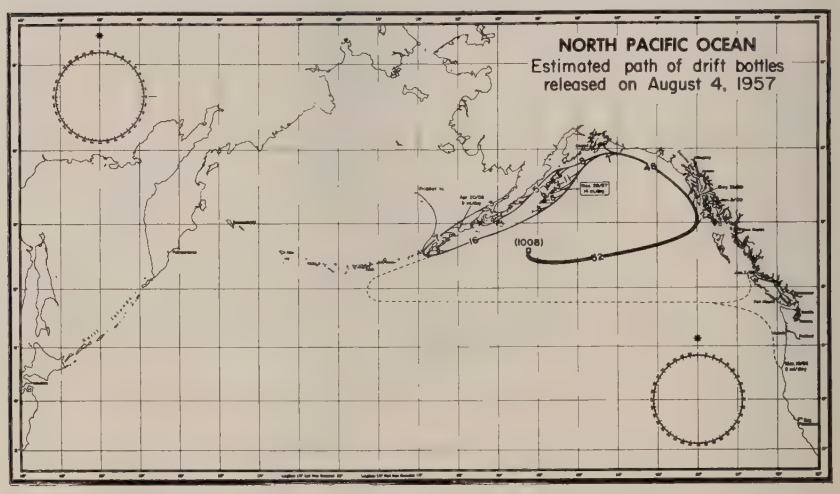


FIGURE 139. Drift bottle releases in central Subarctic.





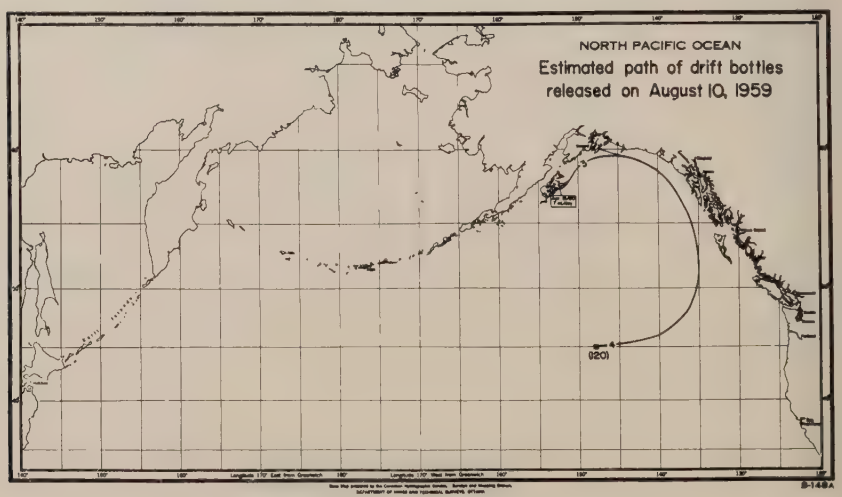


FIGURE 140. Drift bottle releases in eastern Subarctic.

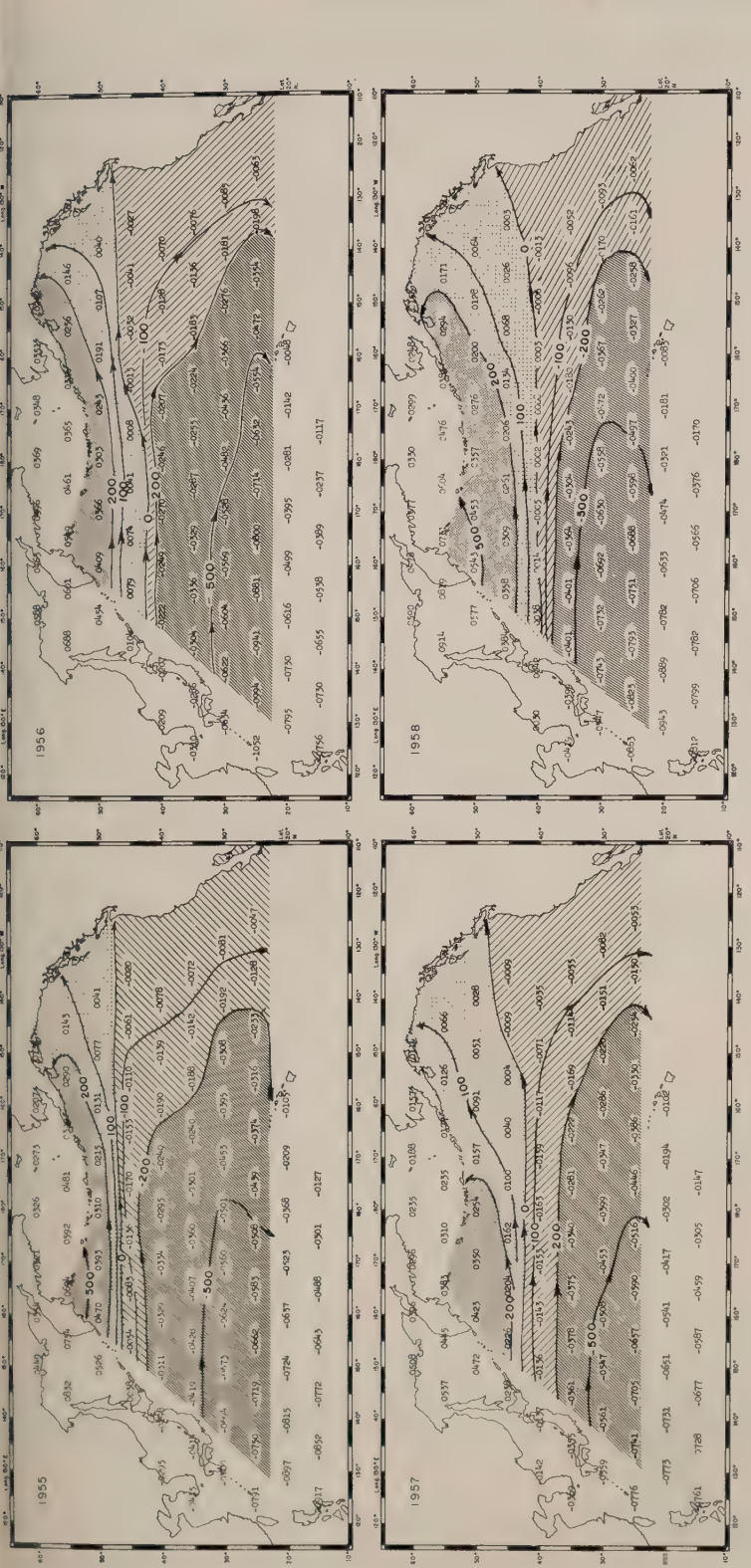


FIGURE 141. Annual mean geostrophic transports, 1955 through 1959.

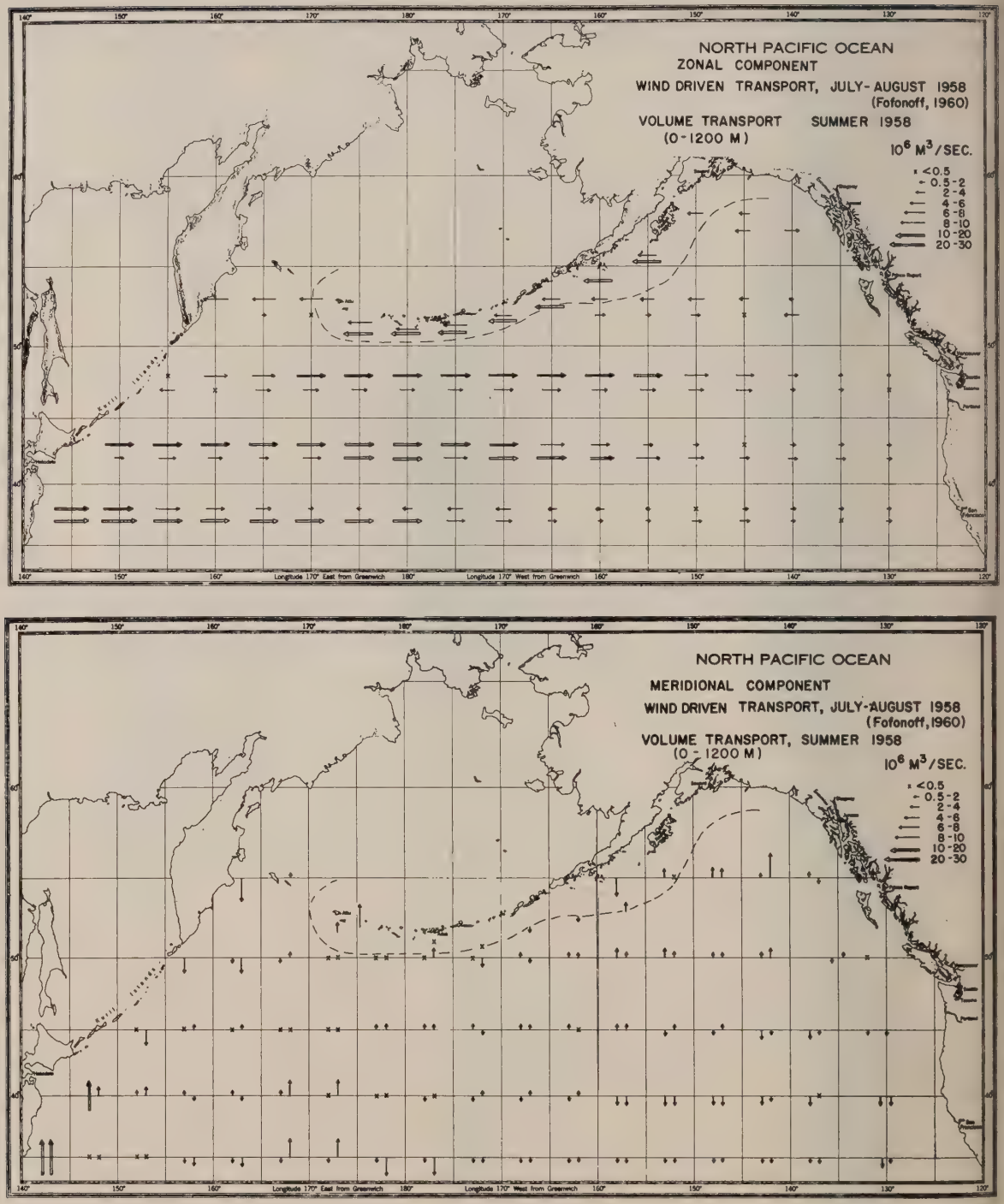


FIGURE 142. Comparison of wind stress and volume transports, summer 1958. Dashed line shows approximate extent of Alaskan Stream.

Upper: Comparison of zonal components of geostrophic mass transport computed from wind stress (upper arrow in each set) and volume transport computed from hydrographic data from 0 to 1200 metres (lower arrow in each set).

Lower: Comparison of meridional components of geostrophic mass transport computed from wind stress (left arrow in each set) and volume transport computed from hydrographic data from 0 to 1200 metres (right arrow in each set).

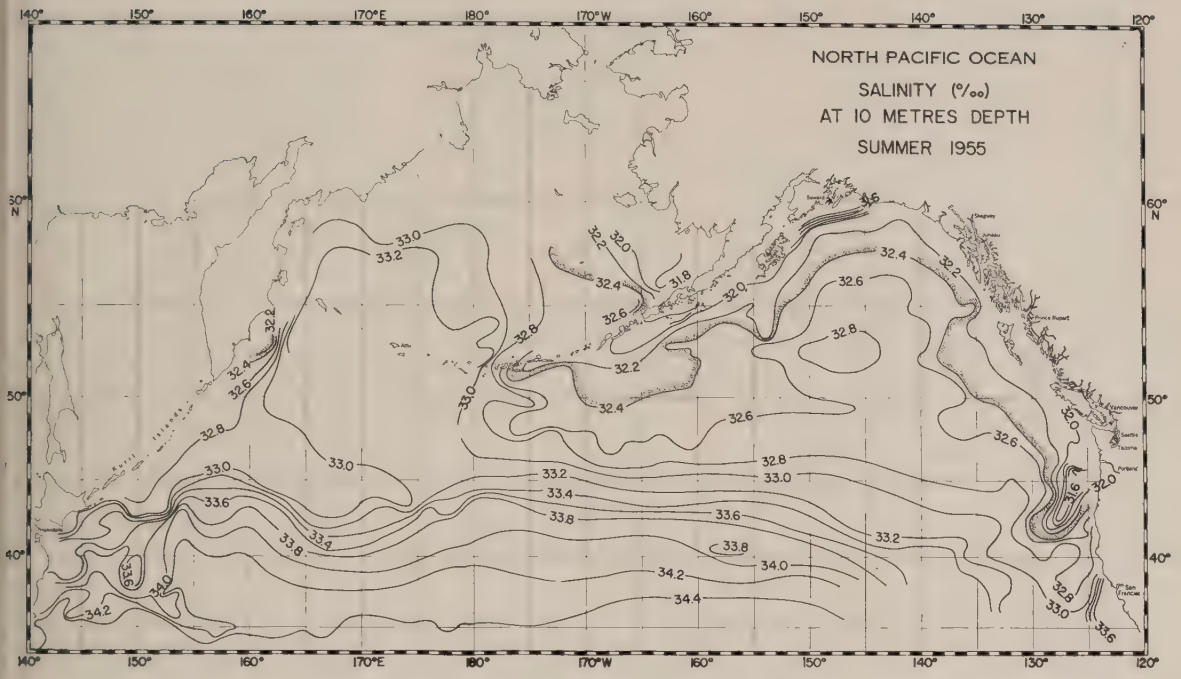


FIGURE 143. Salinity at 10 metres depth, summer 1955.

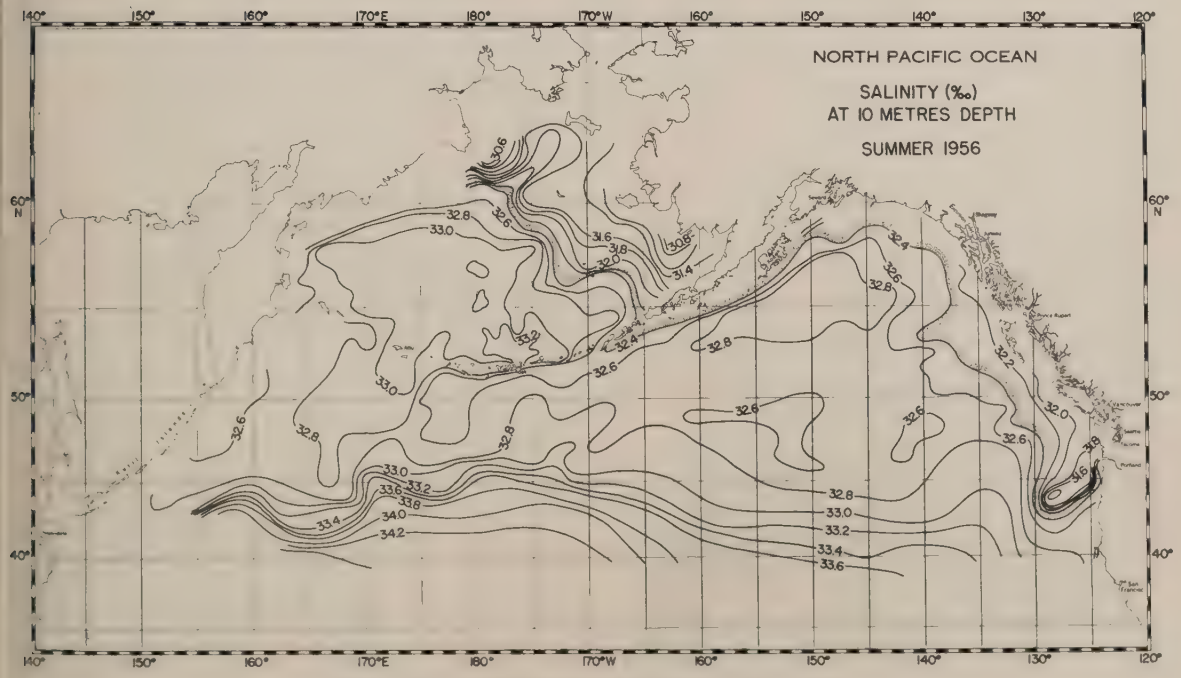


FIGURE 144. Salinity at 10 metres depth, summer 1956.

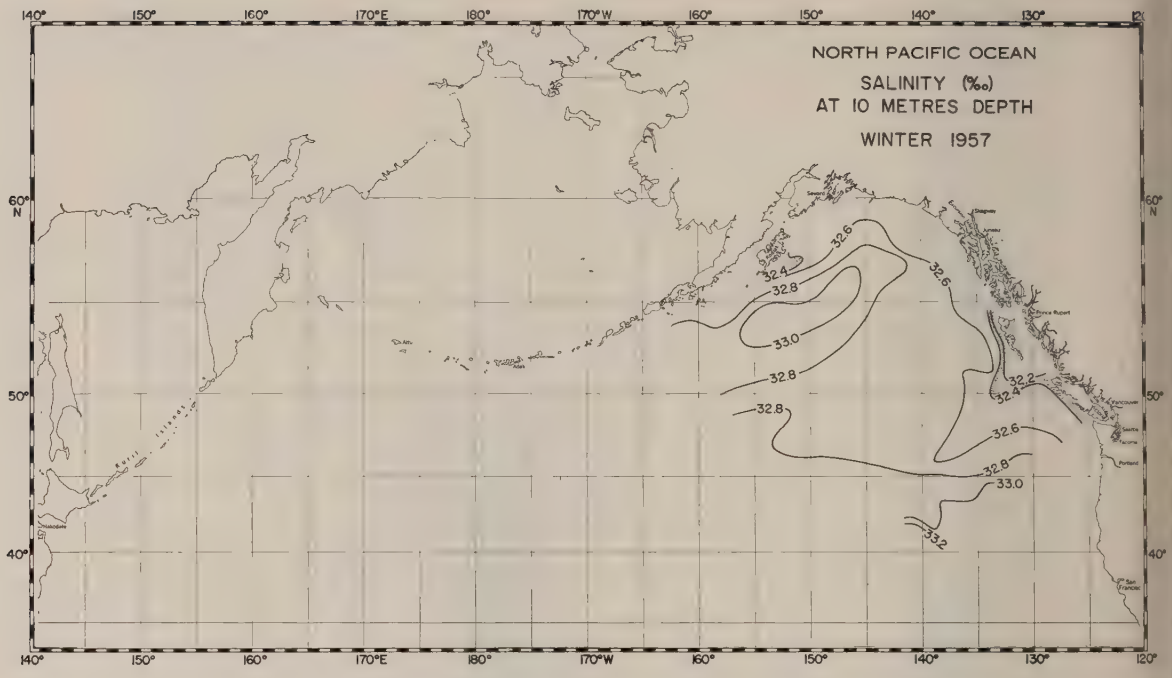


FIGURE 145. Salinity at 10 metres depth, winter 1957.

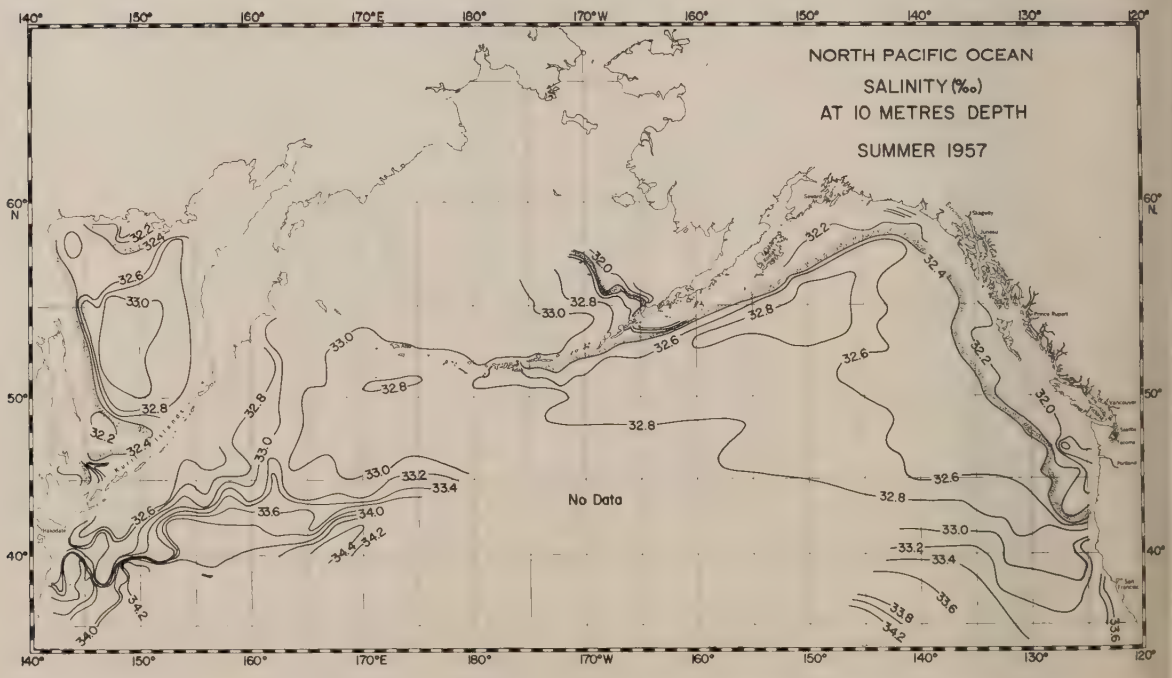


FIGURE 146. Salinity at 10 metres depth, summer 1957.

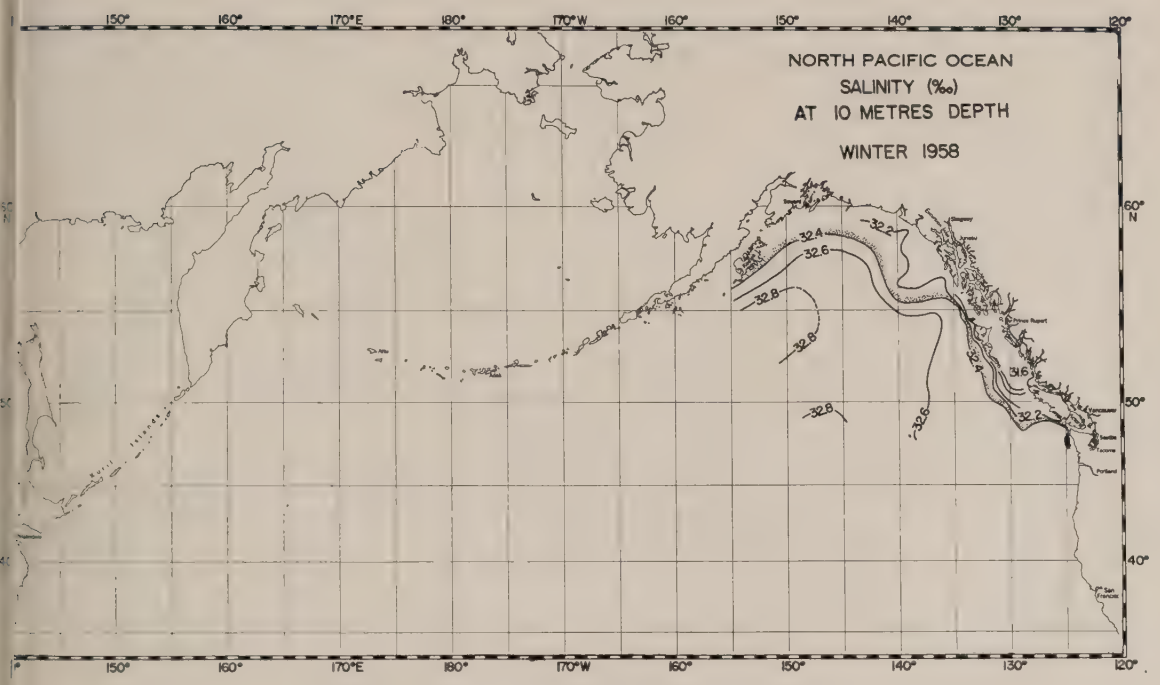


FIGURE 147. Salinity at 10 metres depth, winter 1958.

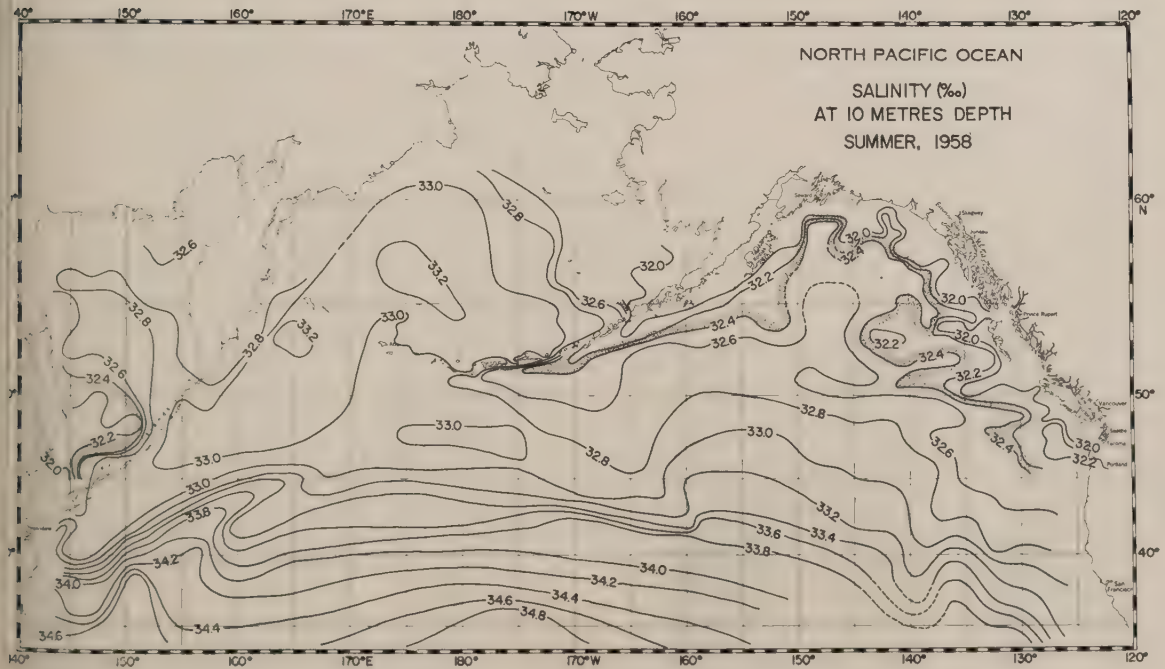


FIGURE 148. Salinity at 10 metres depth, summer 1958.

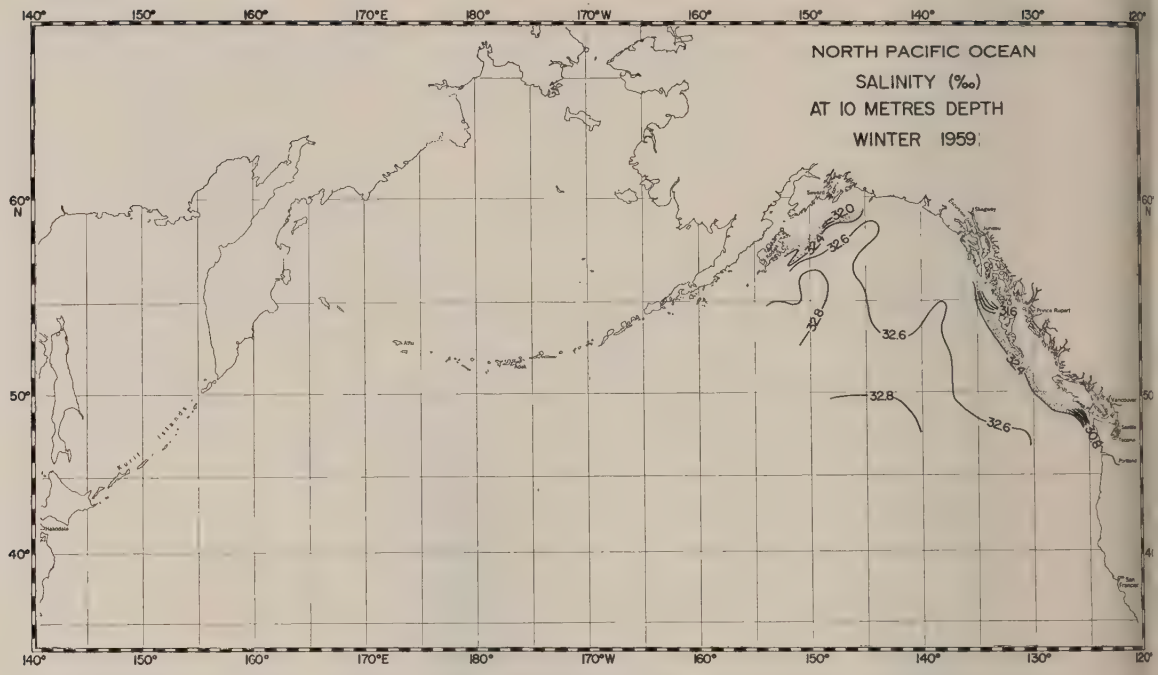


FIGURE 149. Salinity at 10 metres depth, winter 1959.

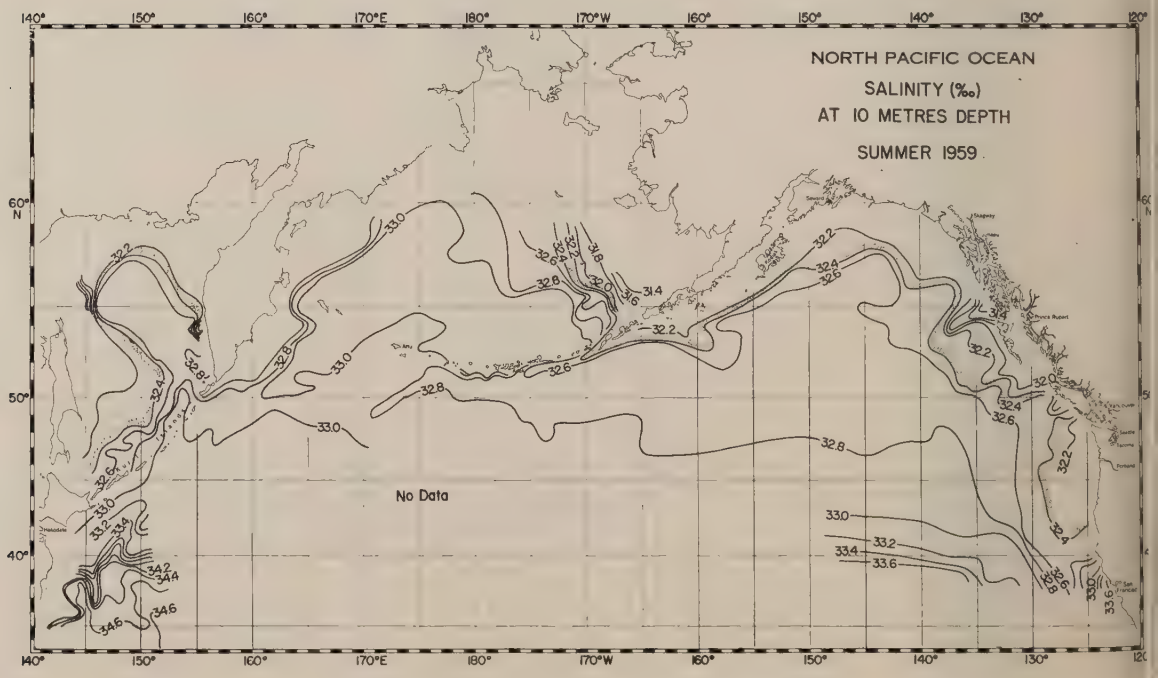


FIGURE 150. Salinity at 10 metres depth, summer 1959.

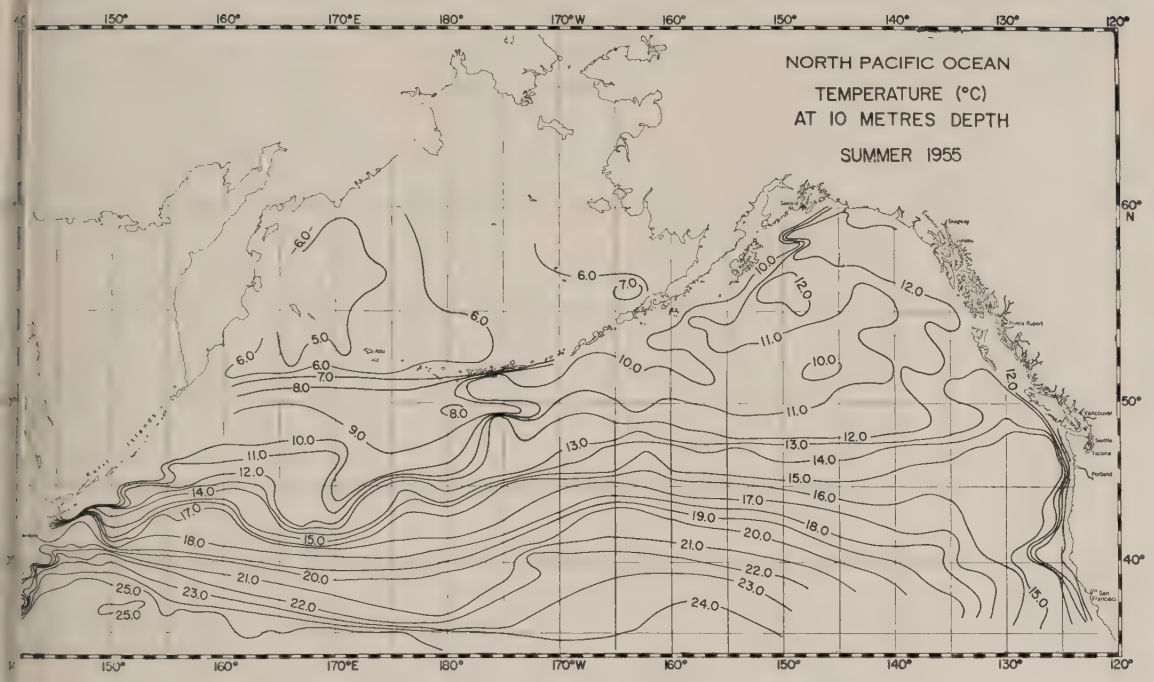


FIGURE 151. Temperature at 10 metres depth, summer 1955.

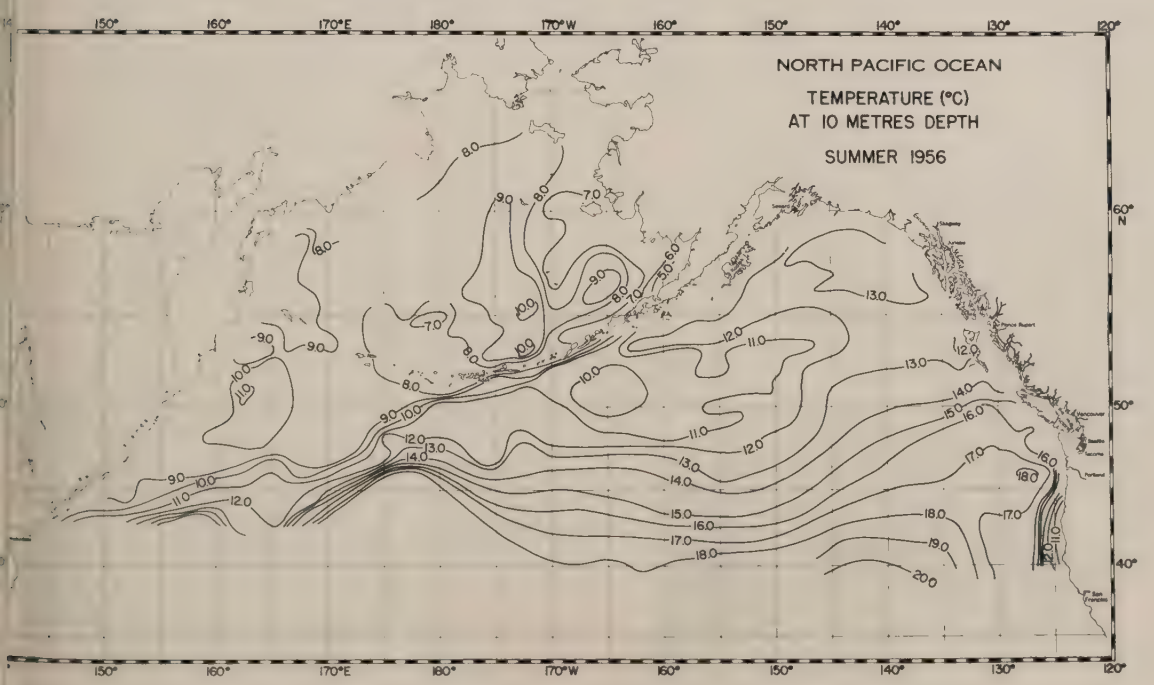


FIGURE 152. Temperature at 10 metres depth, summer 1956.

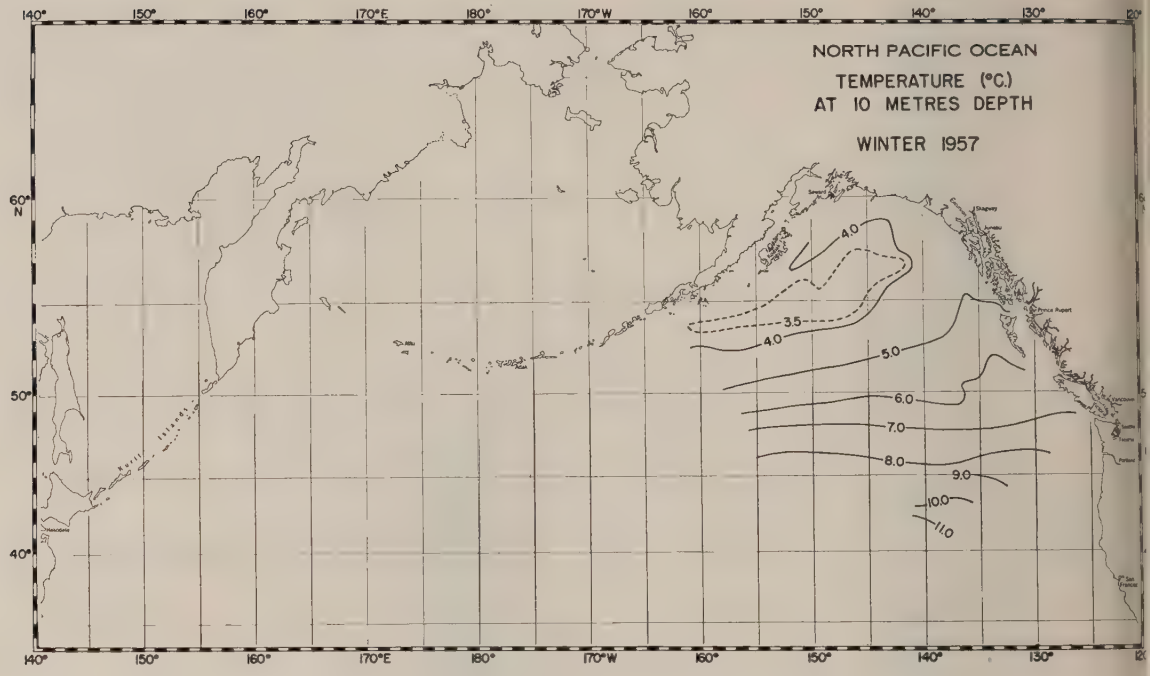


FIGURE 153. Temperature at 10 metres depth, winter 1957.

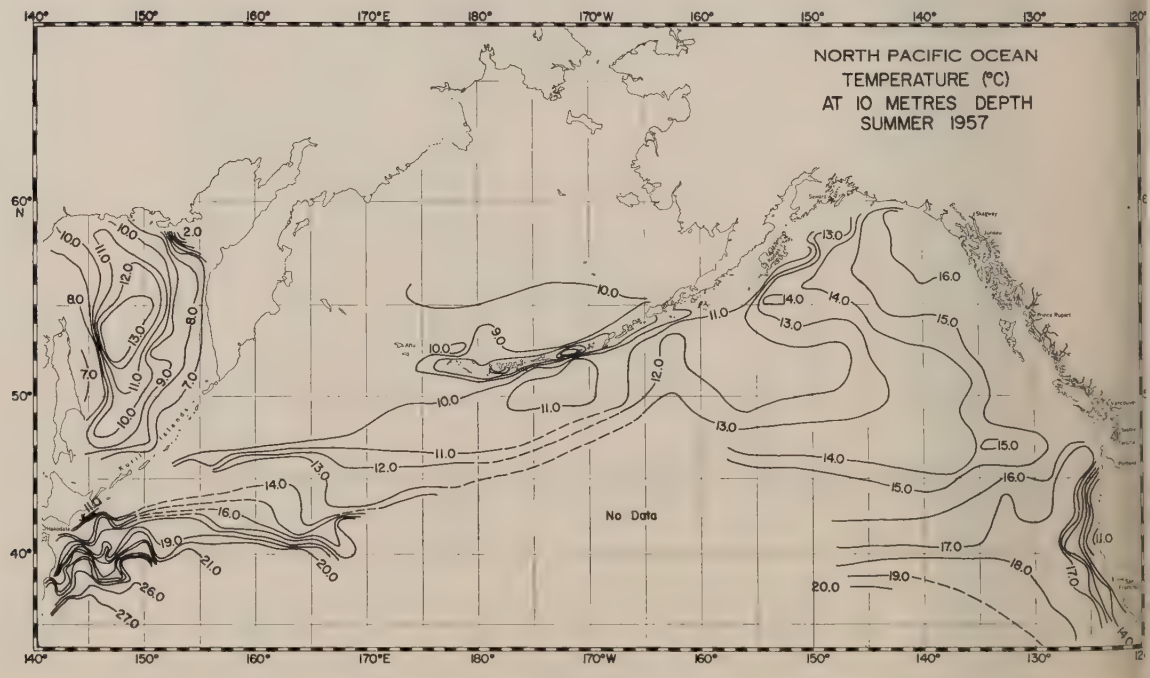


FIGURE 154. Temperature at 10 metres depth, summer 1957.

FIGURE 155. Temperature at 10 metres depth, winter 1958.

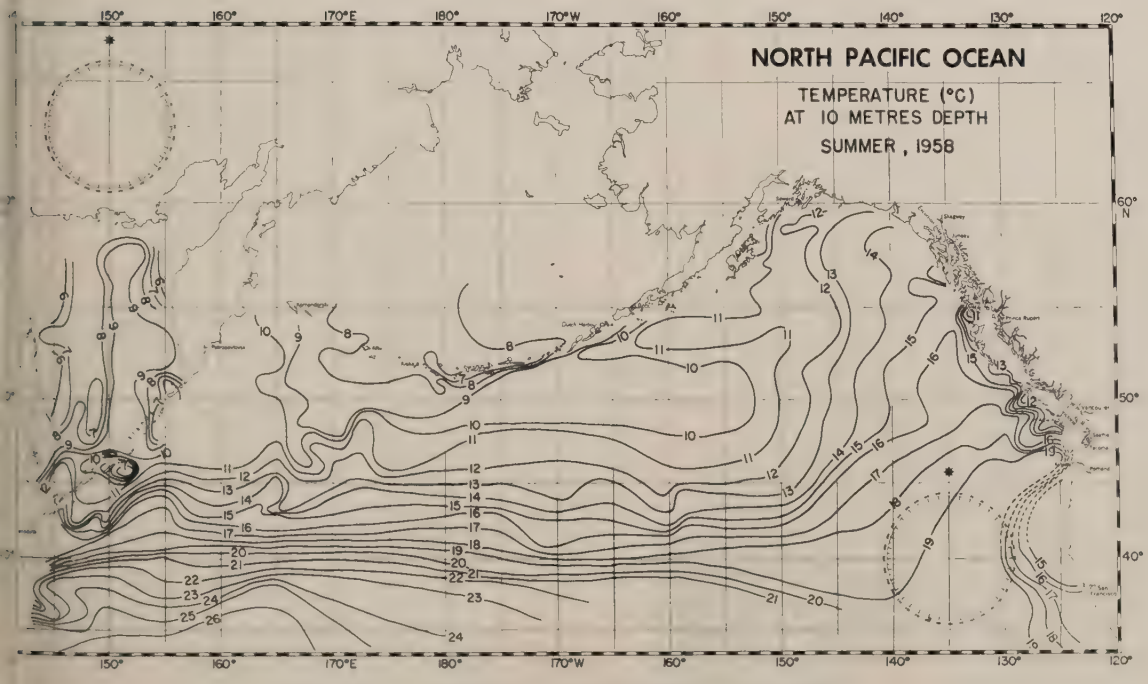


FIGURE 156. Temperature at 10 metres depth, summer 1958.

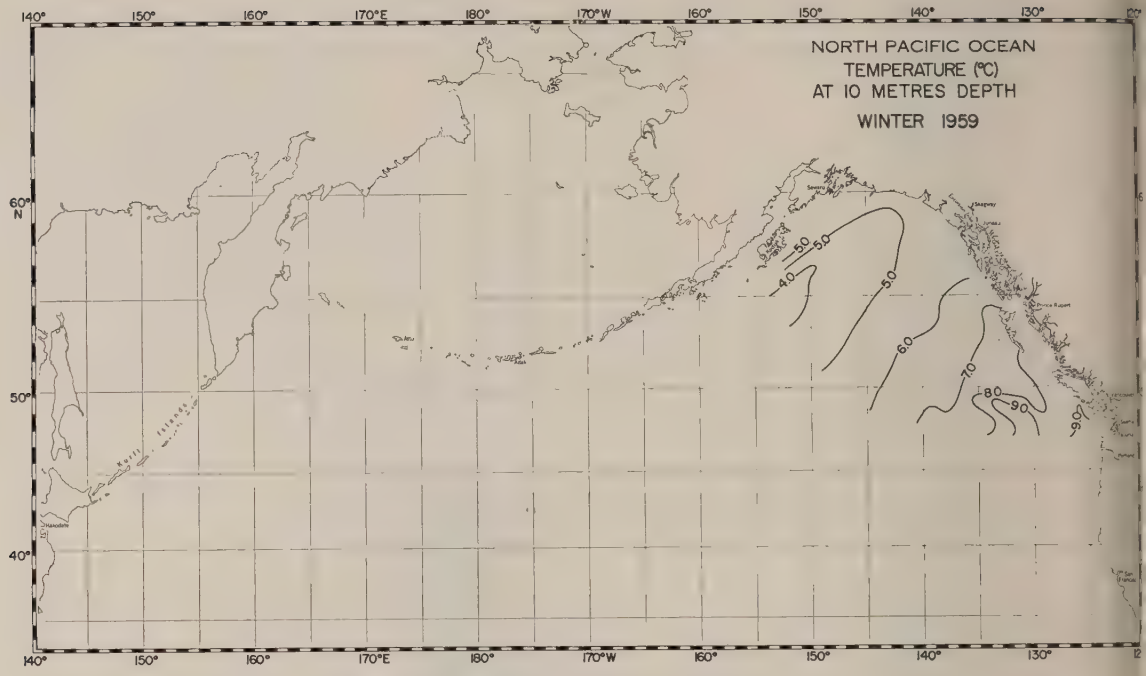


FIGURE 157. Temperature at 10 metres depth, winter 1959.

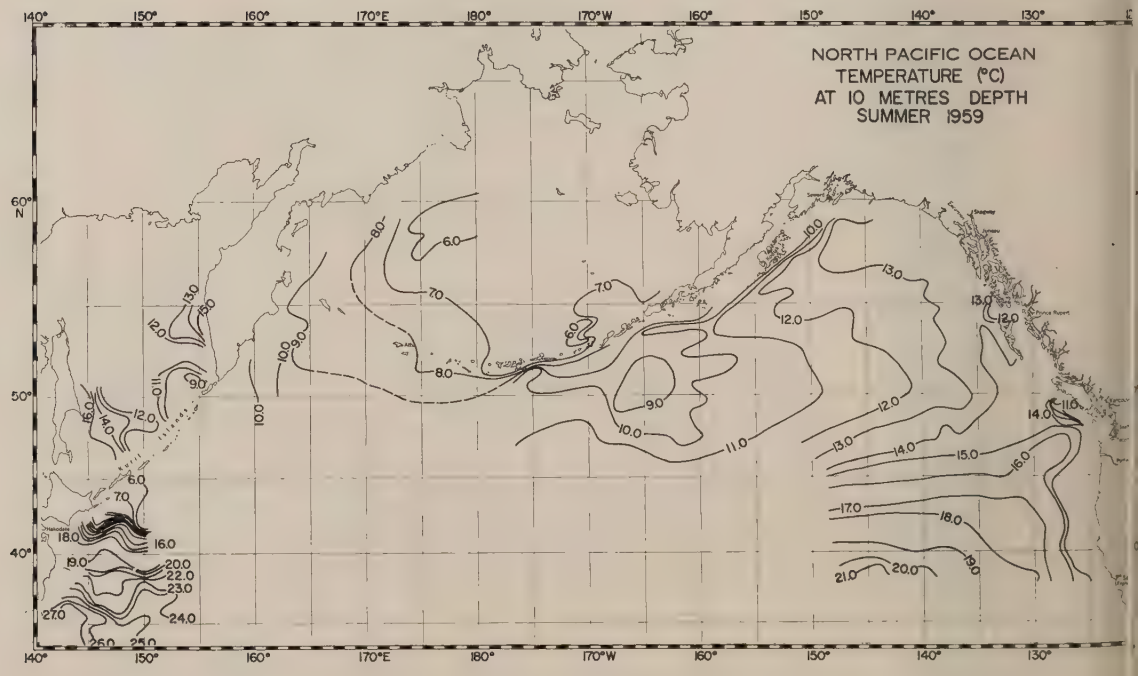


FIGURE 158. Temperature at 10 metres depth, summer 1959.

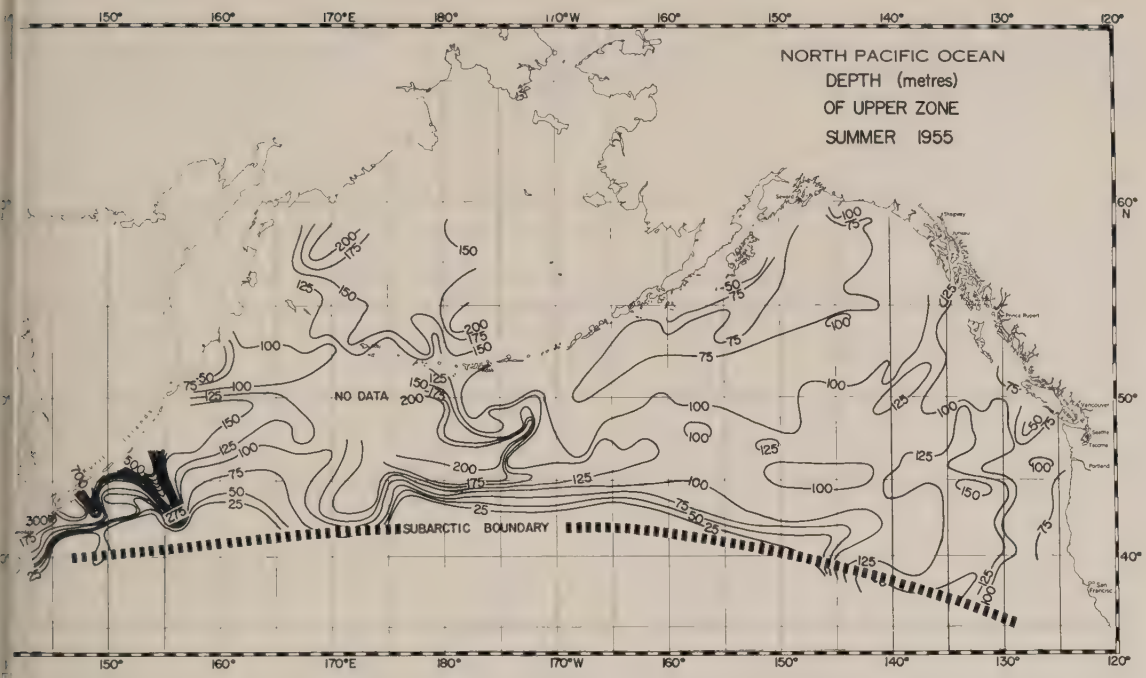


FIGURE 159. Depth (metres) of upper zone, summer 1955.

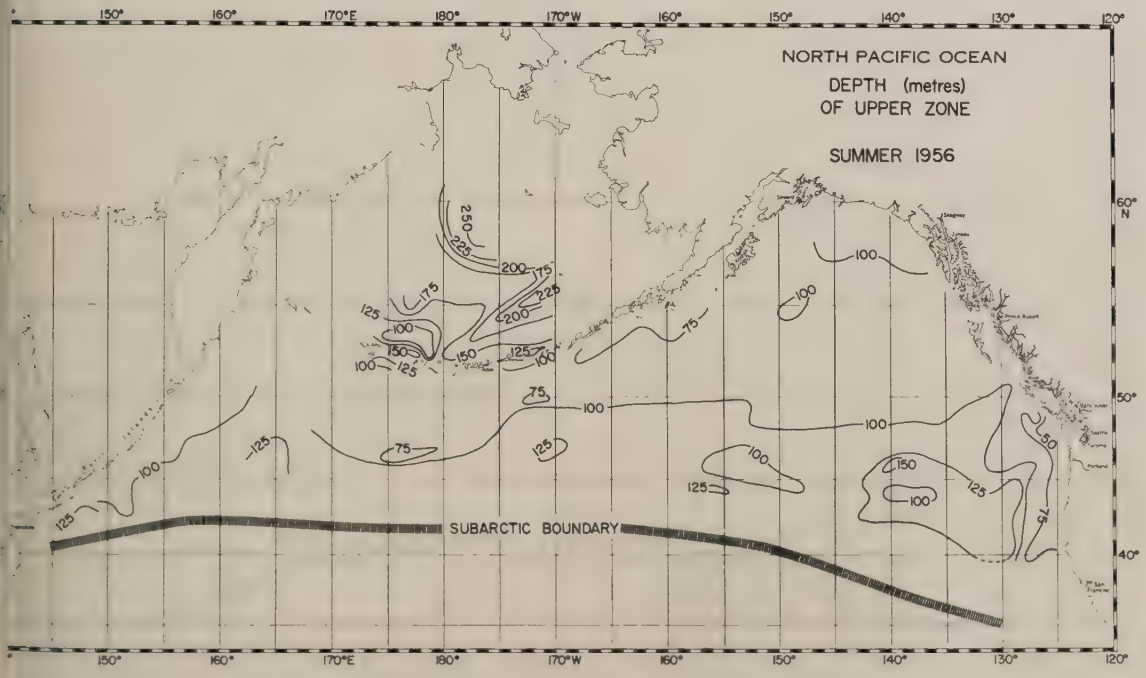


FIGURE 160. Depth (metres) of upper zone, summer 1956.

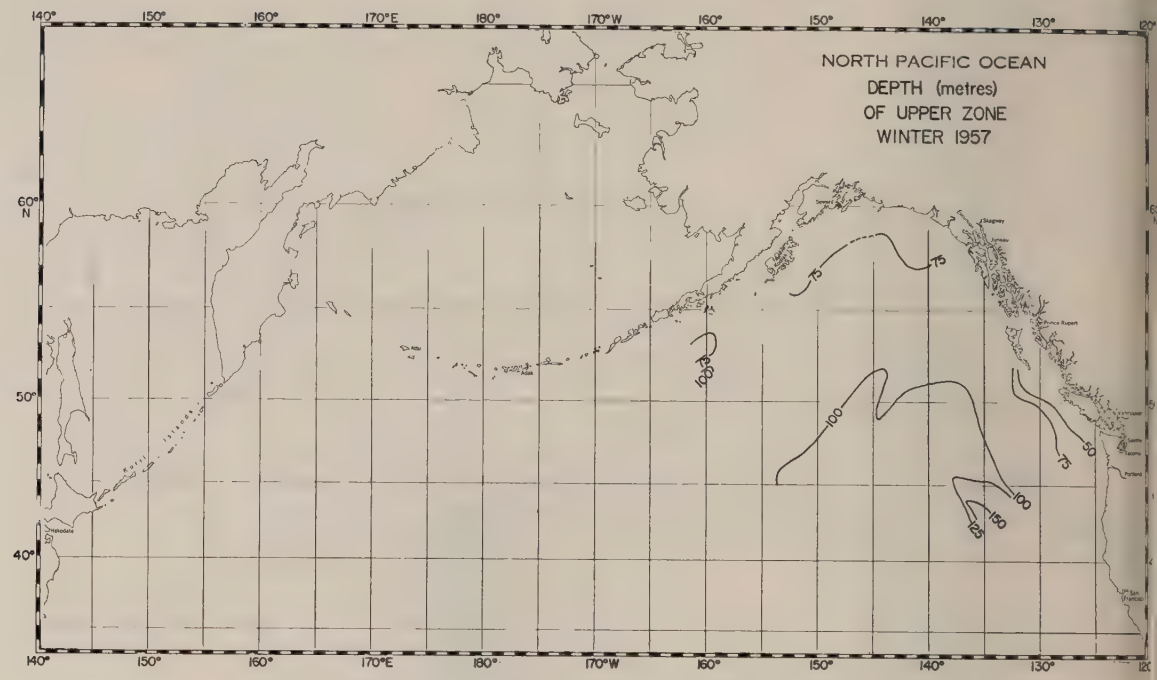


FIGURE 161. Depth (metres) of upper zone, winter 1957.

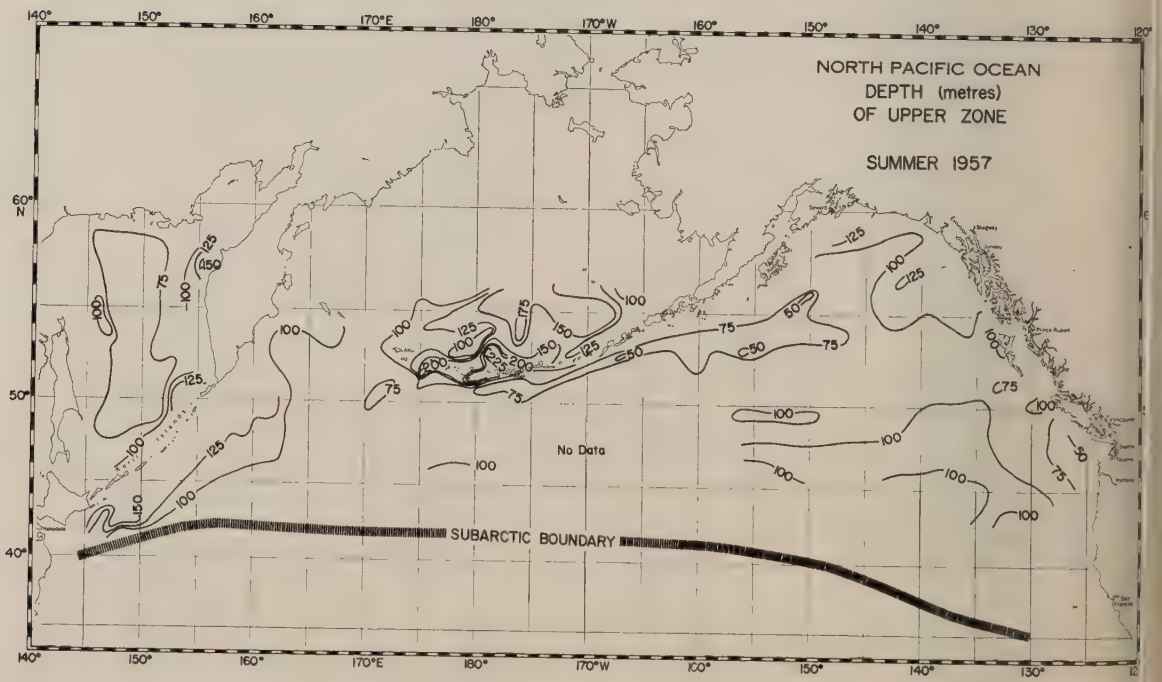


FIGURE 162. Depth (metres) of upper zone, summer 1957.

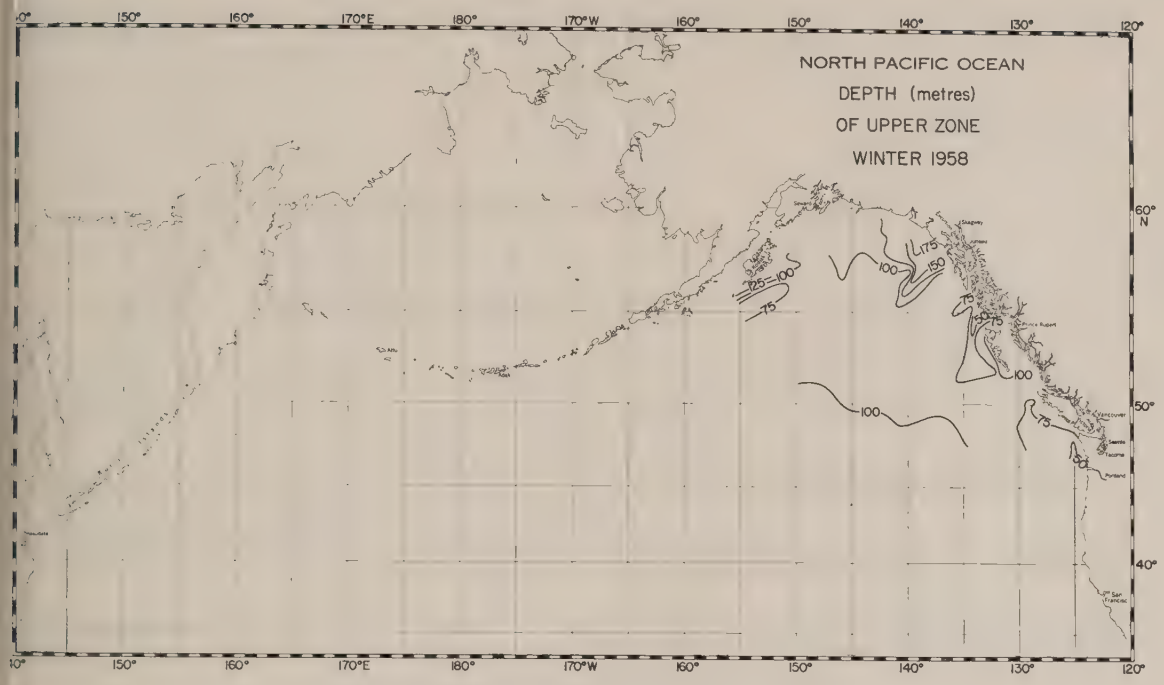


FIGURE 163. Depth (metres) of upper zone, winter 1958.

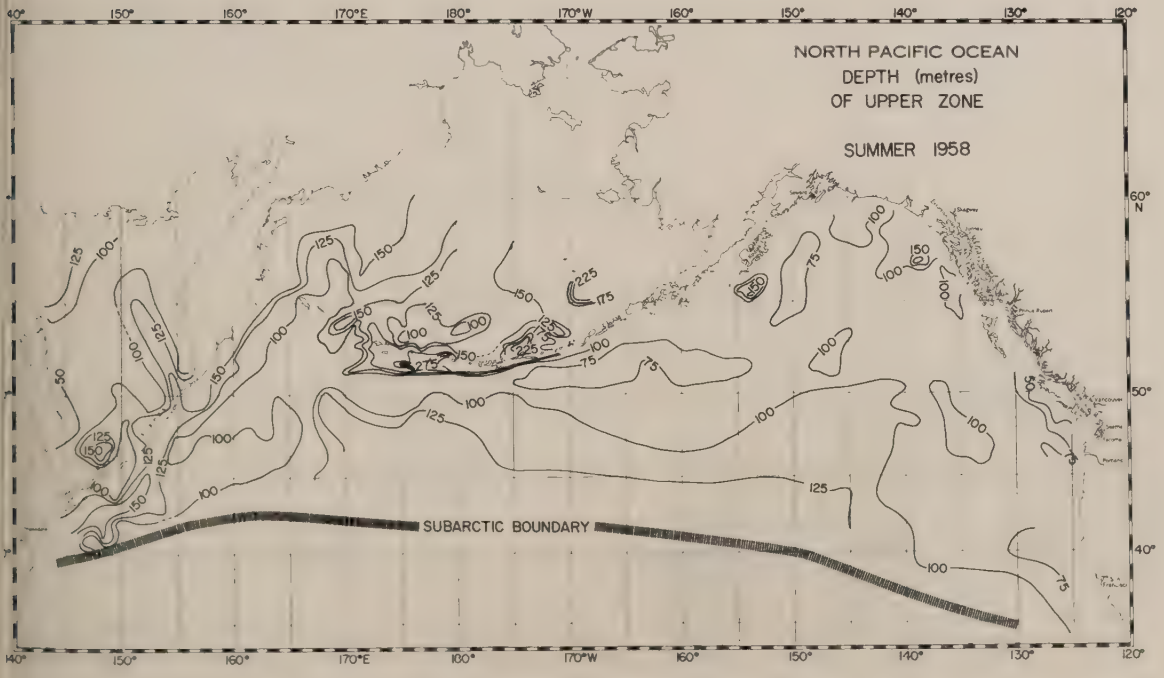


FIGURE 164. Depth (metres) of upper zone, summer 1958.

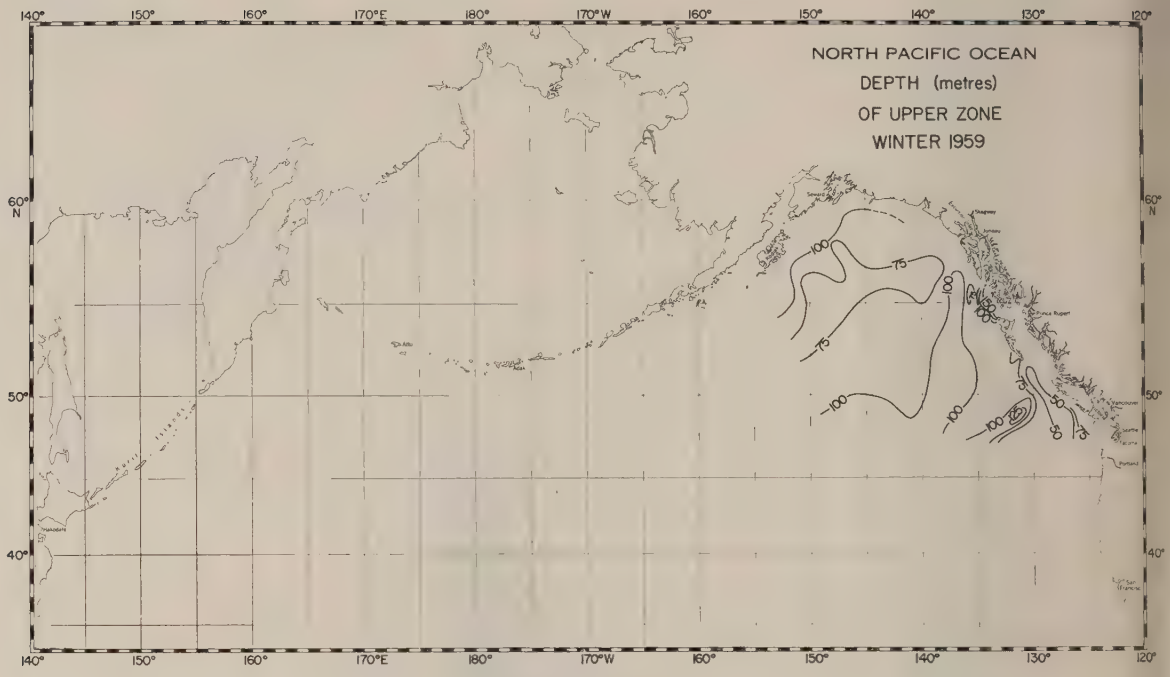


FIGURE 165. Depth (metres) of upper zone, winter 1959.

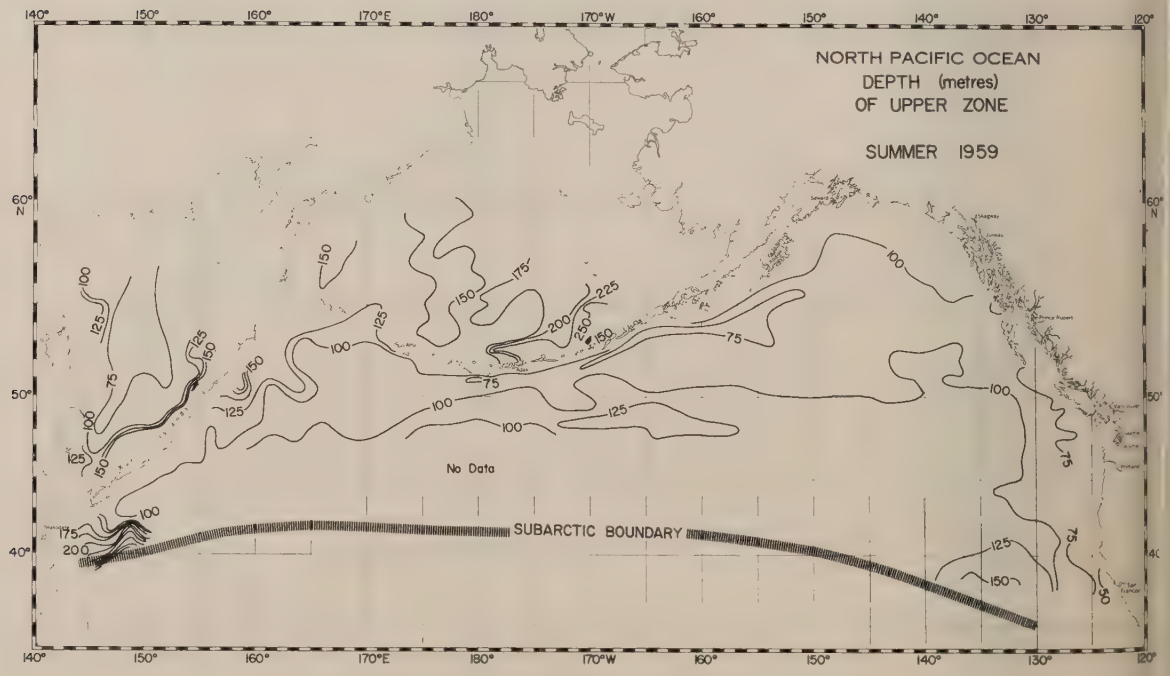


FIGURE 166. Depth (metres) of upper zone, summer 1959.

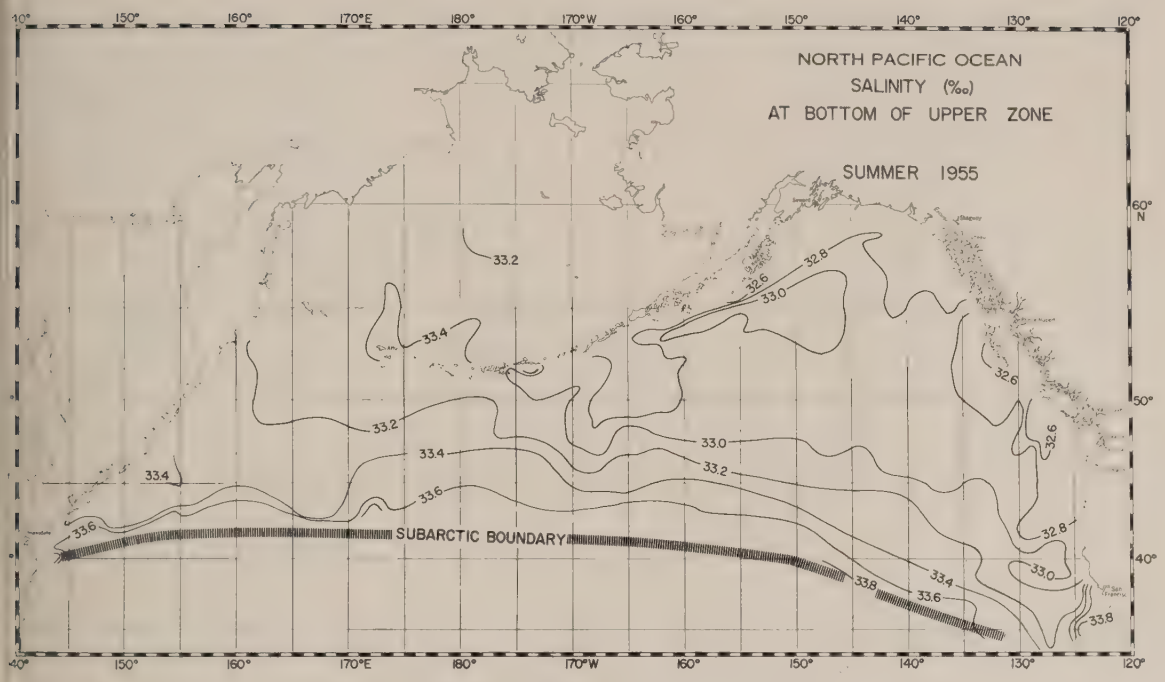


FIGURE 167. Salinity at bottom of upper zone, summer 1955.

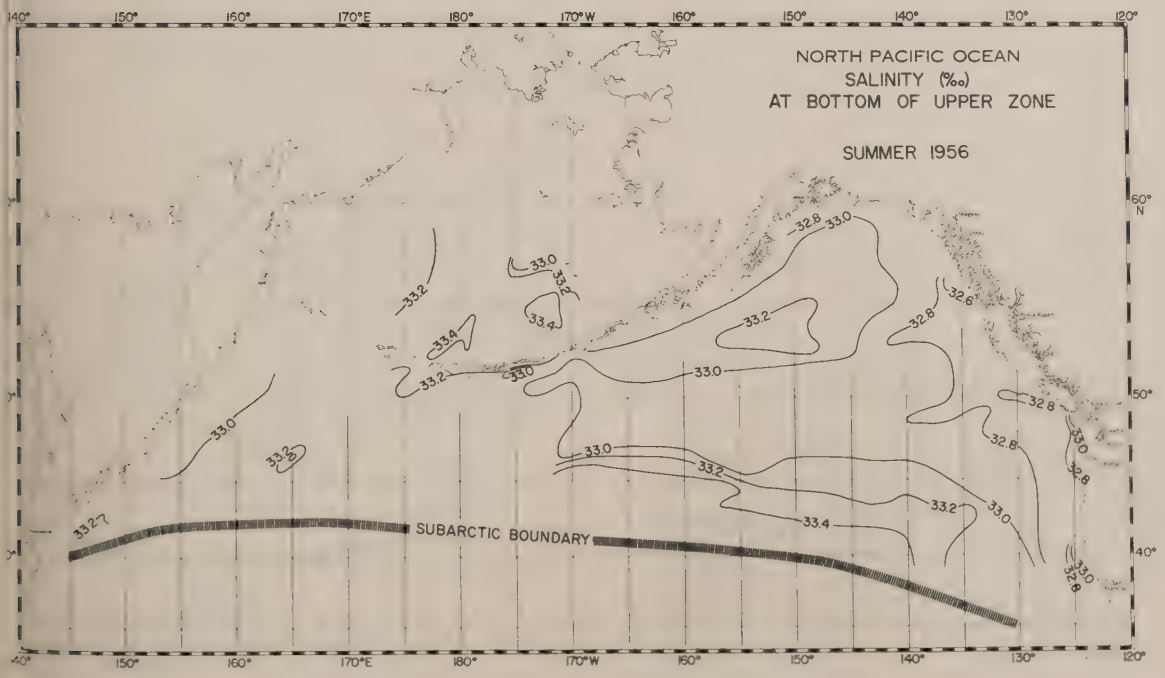


FIGURE 168. Salinity at bottom of upper zone, summer 1956.

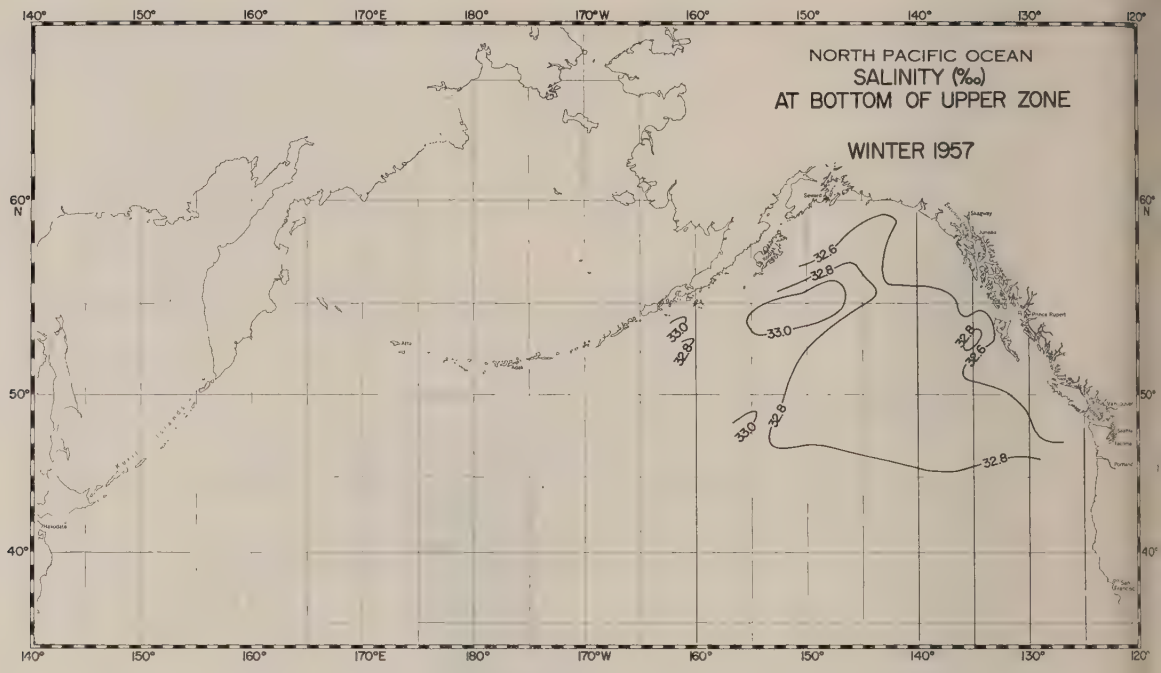


FIGURE 169. Salinity at bottom of upper zone, winter 1957.

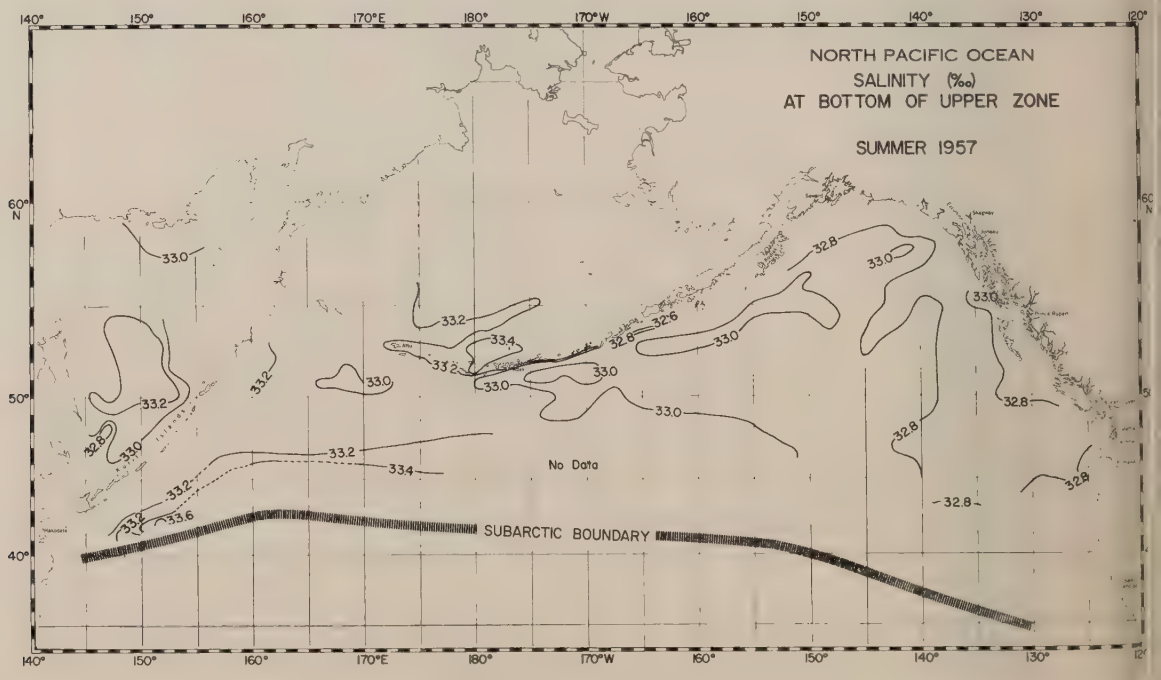


FIGURE 170. Salinity at bottom of upper zone, summer 1957.

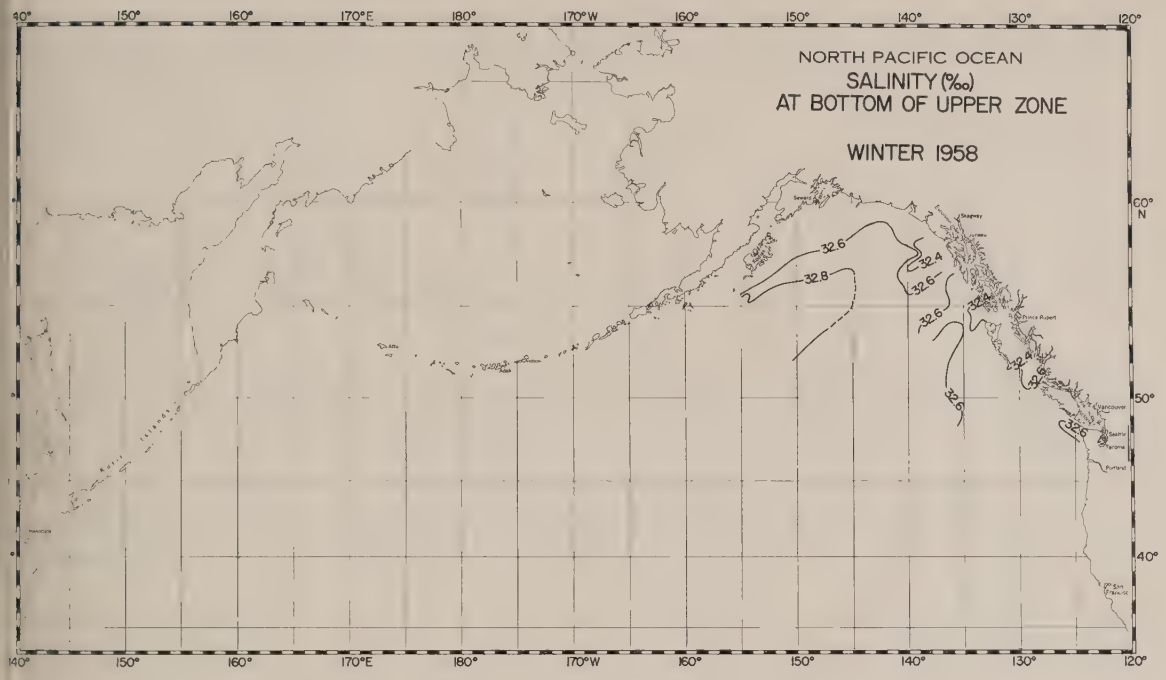

NORTH PACIFIC OCEAN
SALINITY (‰)
AT BOTTOM OF UPPER ZONE
WINTER 1958
32.6
32.8
32.4
32.6
32.6
32.4
32.6
32.6
32.6
32.4
32.6
32.6
32.6

FIGURE 173. Salinity at bottom of upper zone, winter 1959.

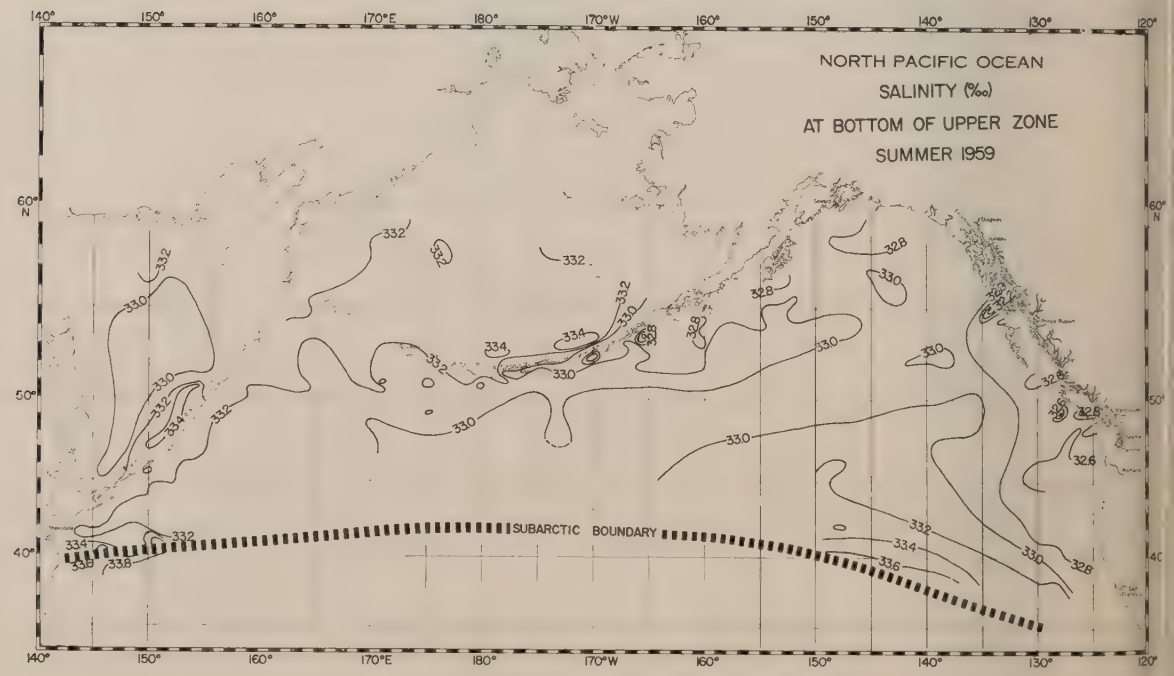


FIGURE 174. Salinity at bottom of upper zone, summer 1959.

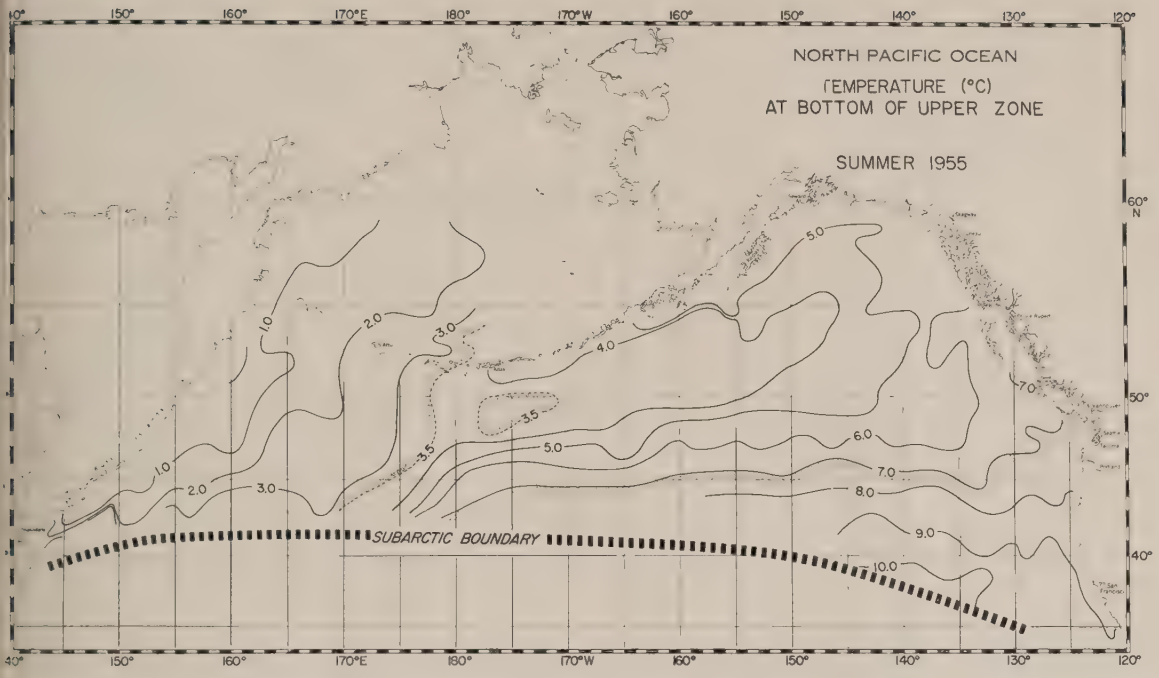


FIGURE 175. Temperature at bottom of upper zone, summer 1955.

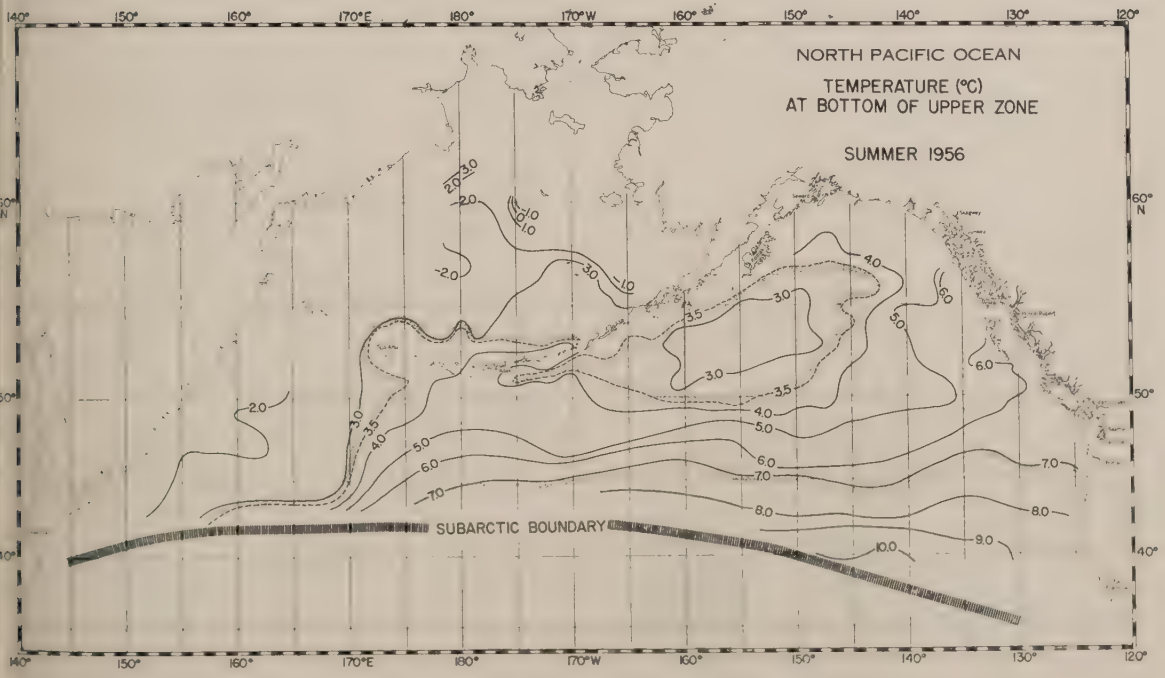


FIGURE 176. Temperature at bottom of upper zone, summer 1956.

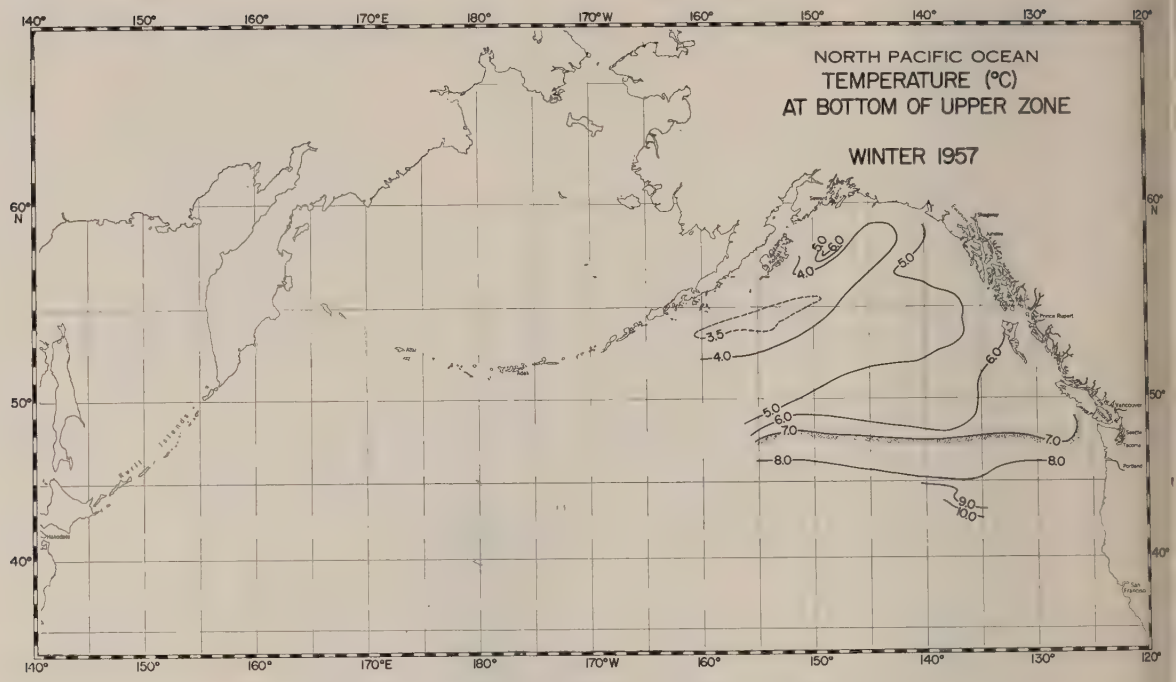


FIGURE 177. Temperature at bottom of upper zone, winter 1957.

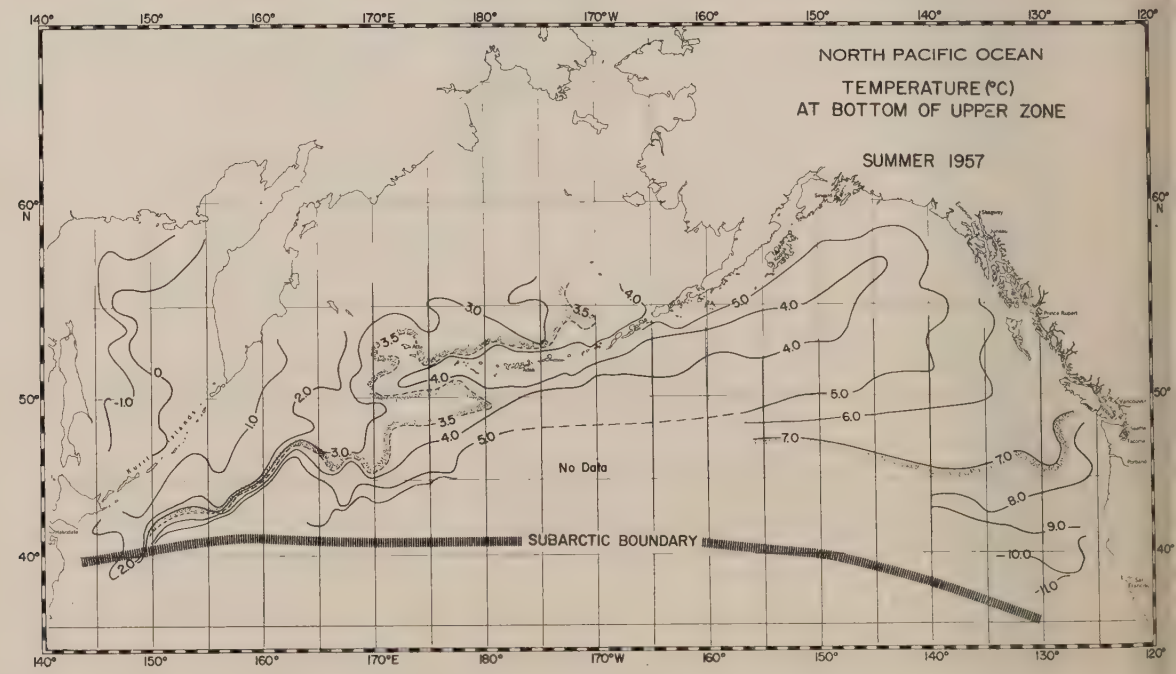


FIGURE 178. Temperature at bottom of upper zone, summer 1957.

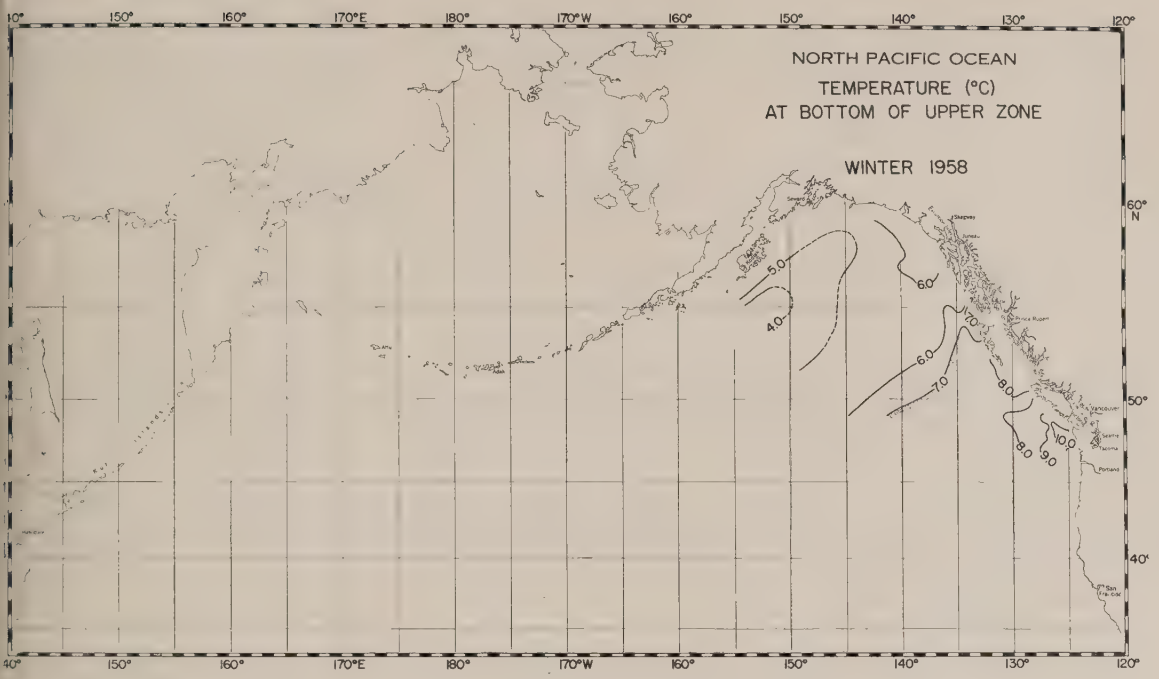


FIGURE 179. Temperature at bottom of upper zone, winter 1958.

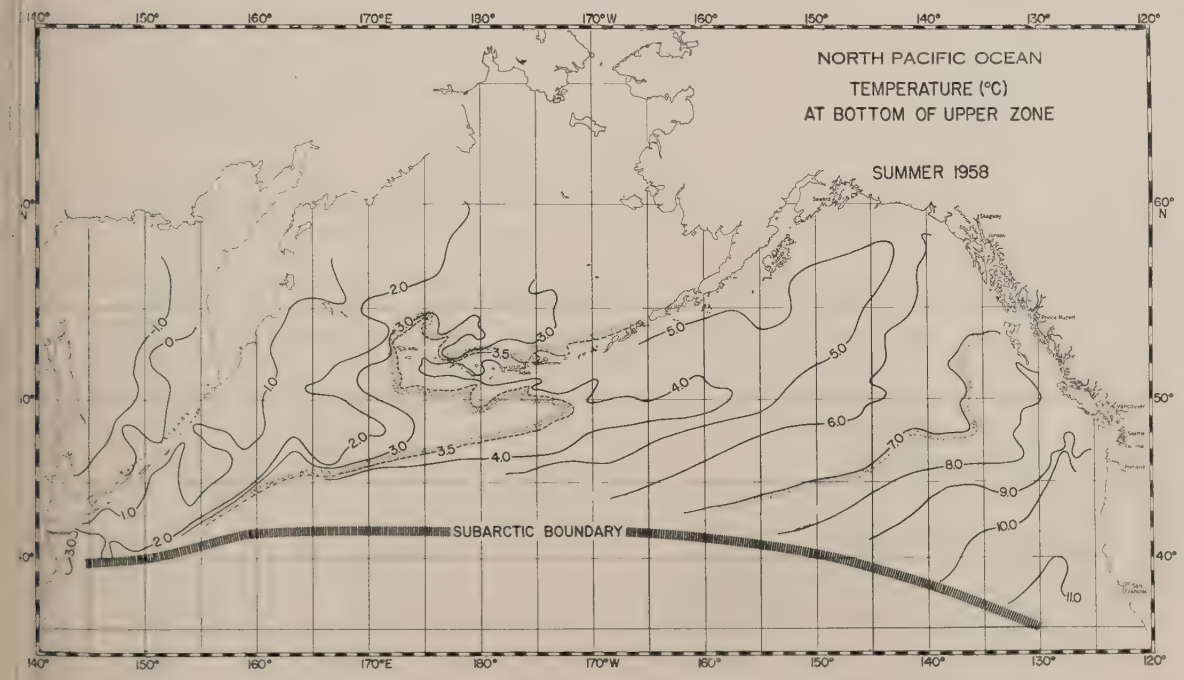


FIGURE 180. Temperature at bottom of upper zone, summer 1958.

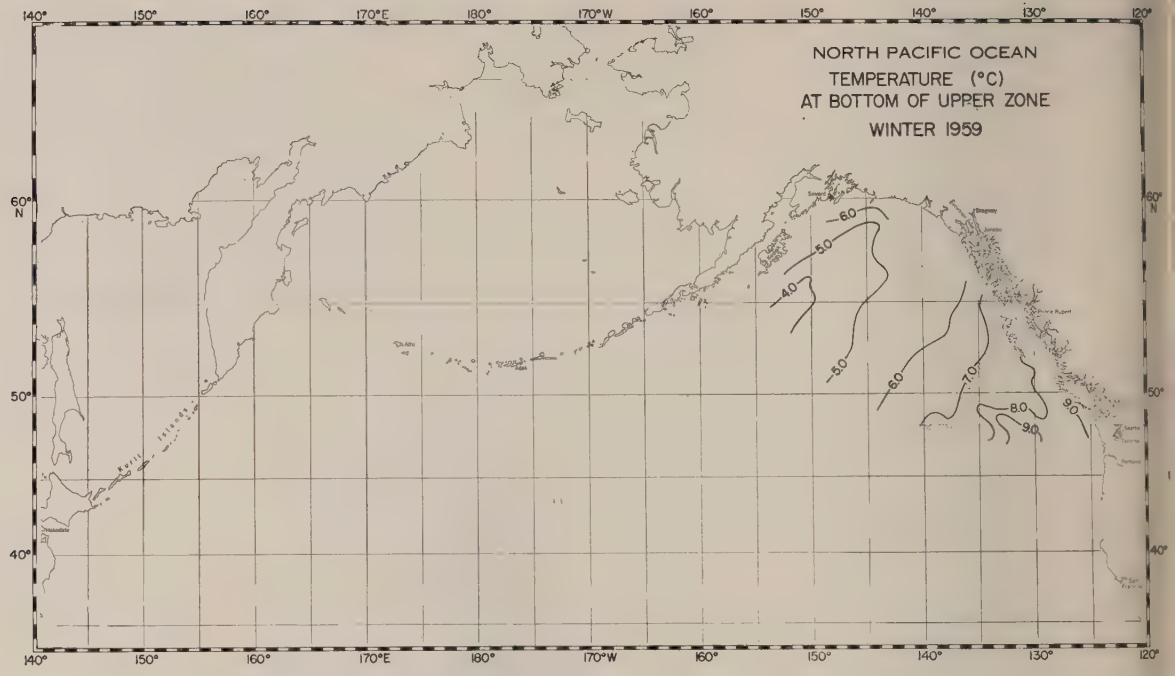


FIGURE 181. Temperature at bottom of upper zone, winter 1959.

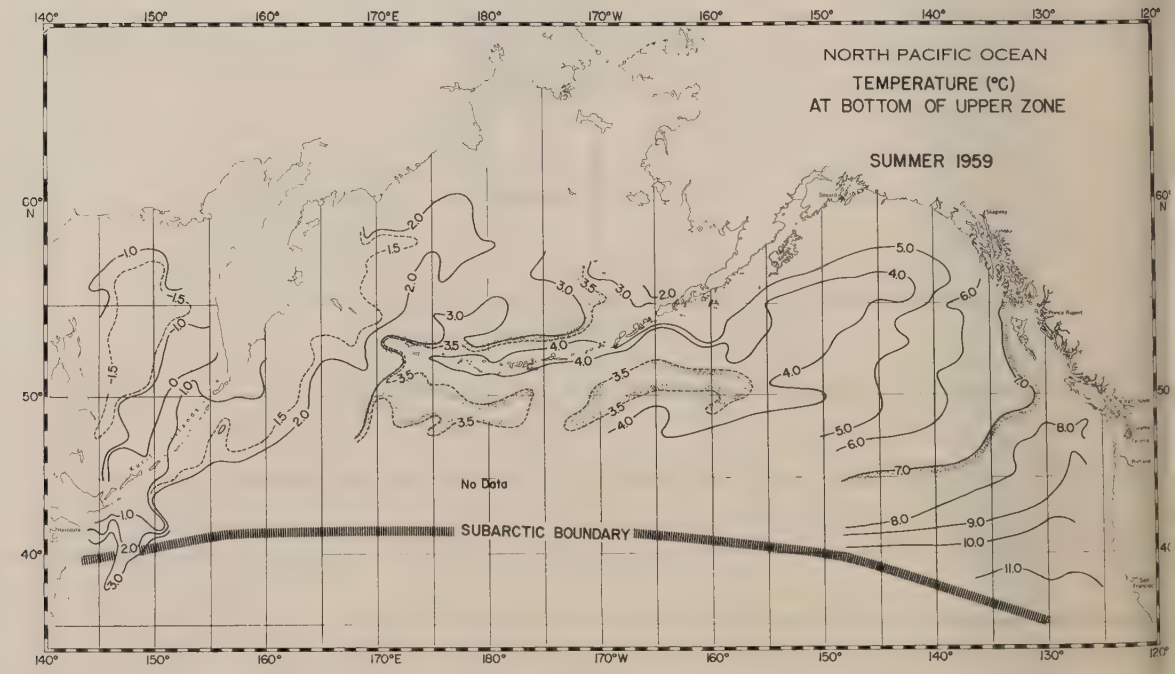


FIGURE 182. Temperature at bottom of upper zone, summer 1959.

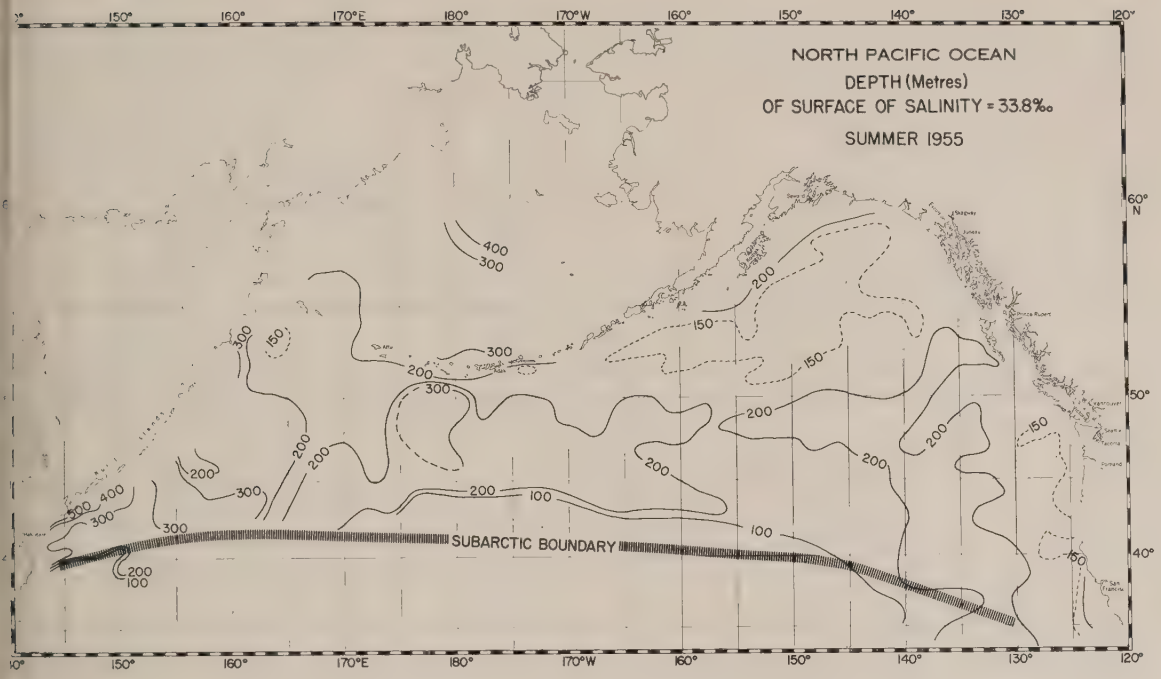


FIGURE 183. Depth (metres) of surface of salinity = 33.8‰, summer 1955.

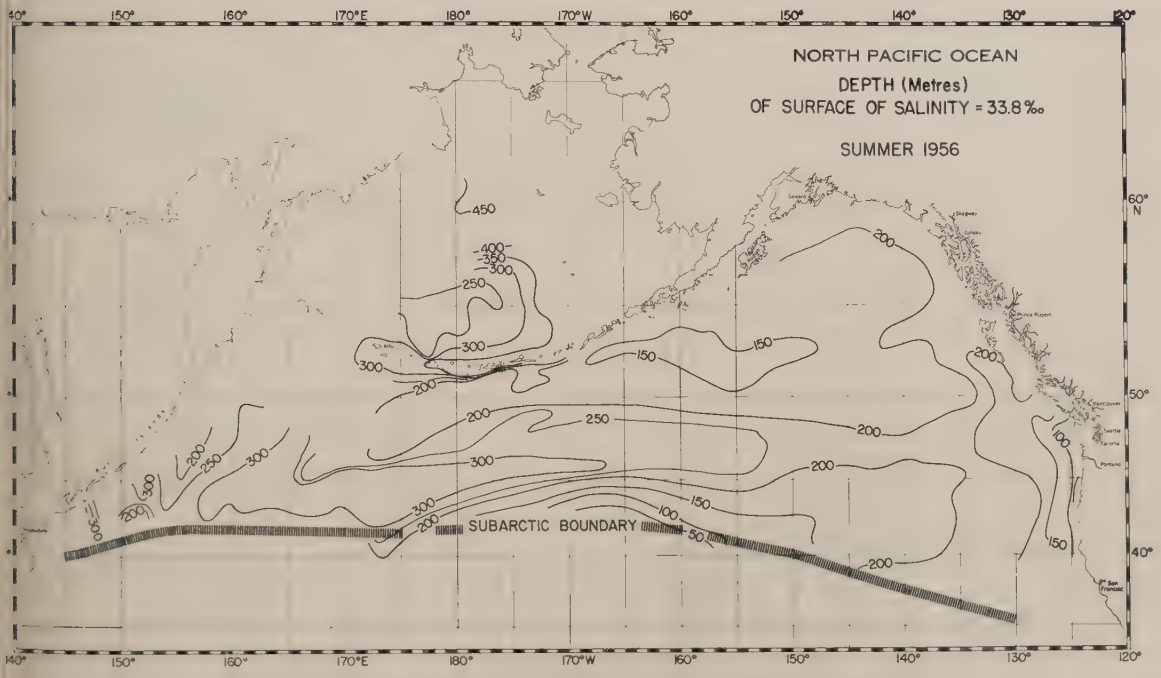


FIGURE 184. Depth (metres) of surface of salinity = 33.8‰, summer 1956.

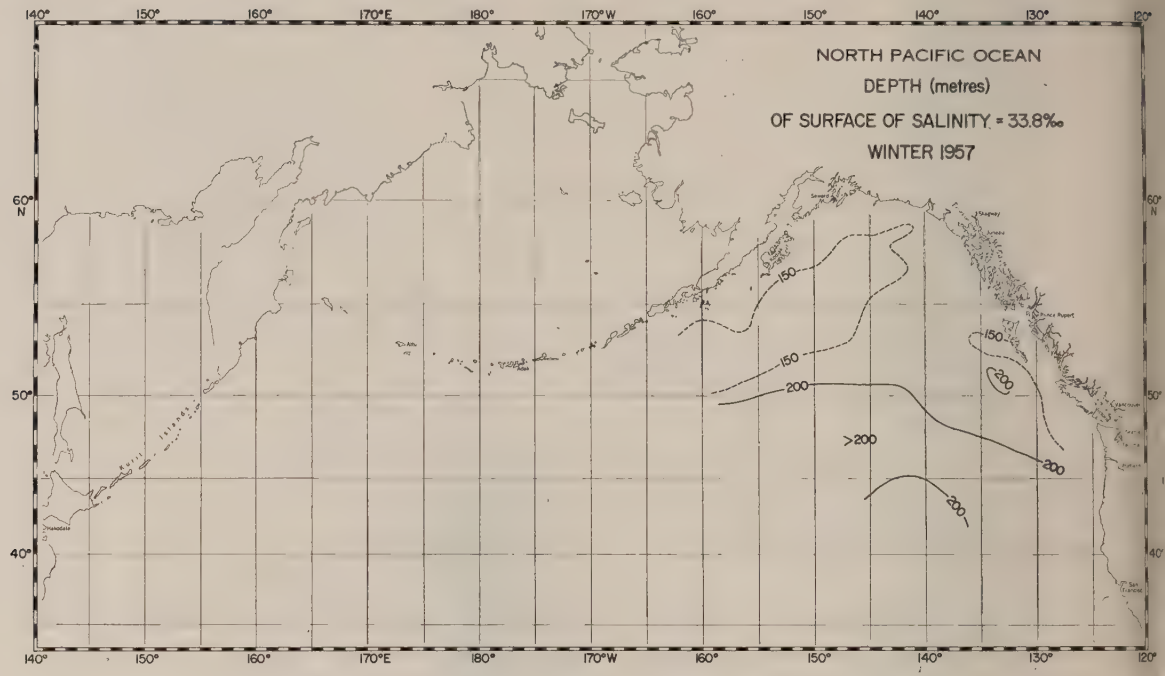


FIGURE 185. Depth (metres) of surface of salinity=33.8‰, winter 1957.

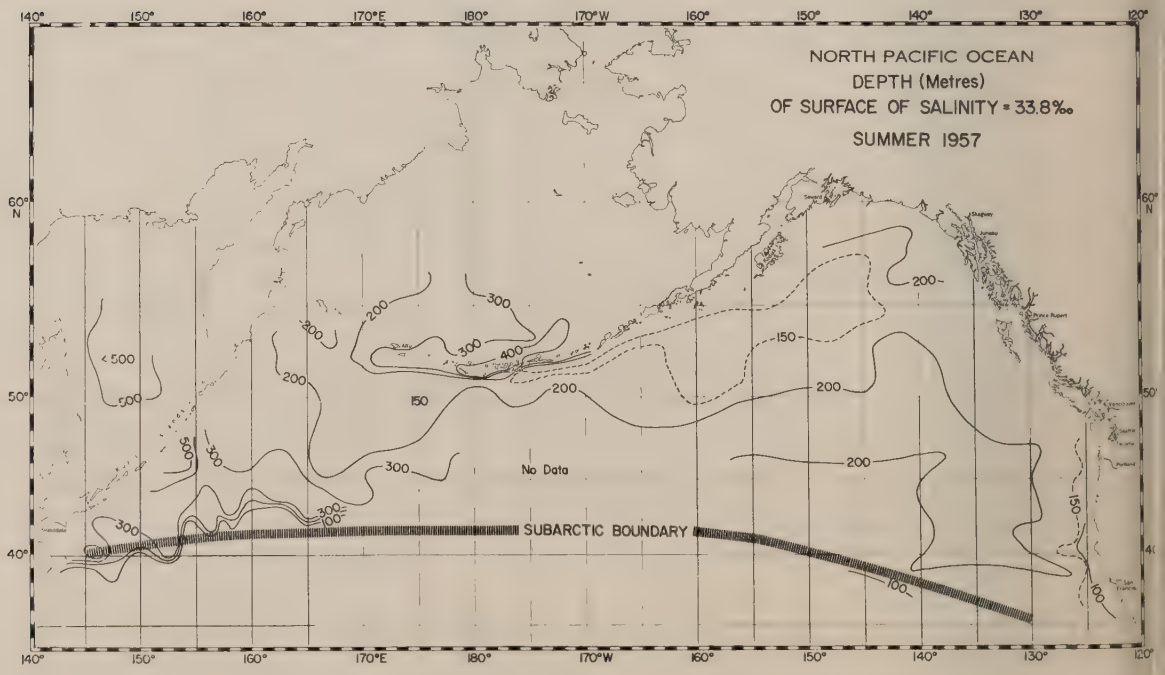


FIGURE 186. Depth (metres) of surface of salinity=33.8‰, summer 1957.

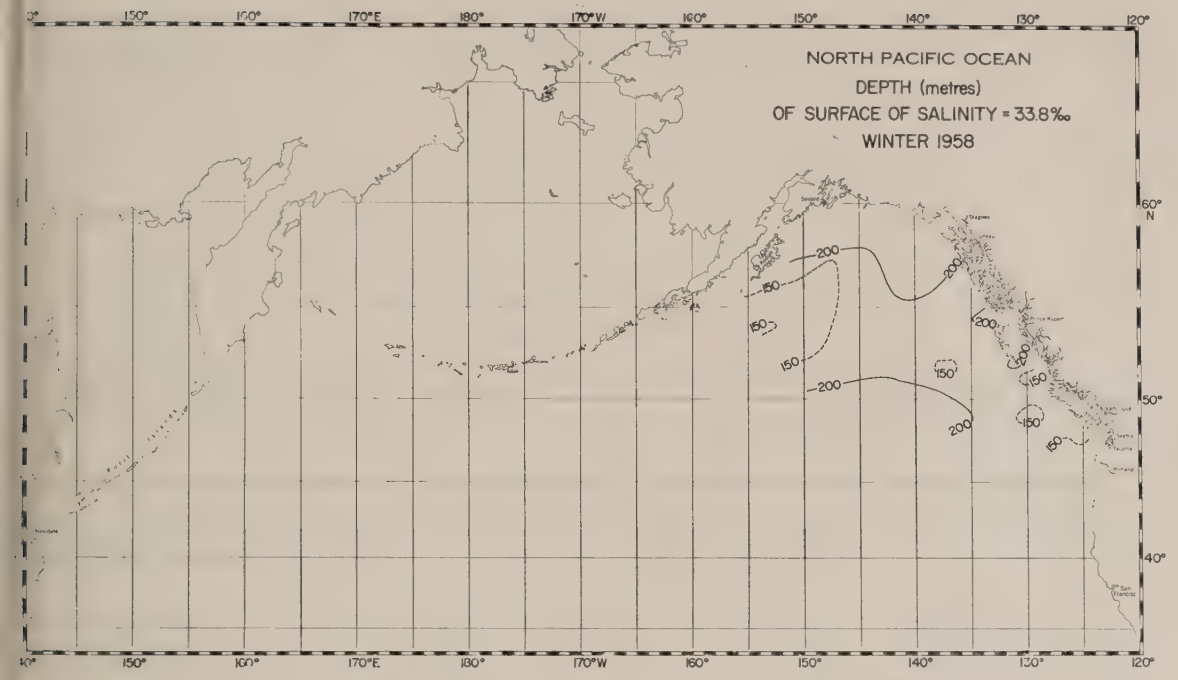


FIGURE 187. Depth (metres) of surface of salinity=33.8‰, winter 1958.

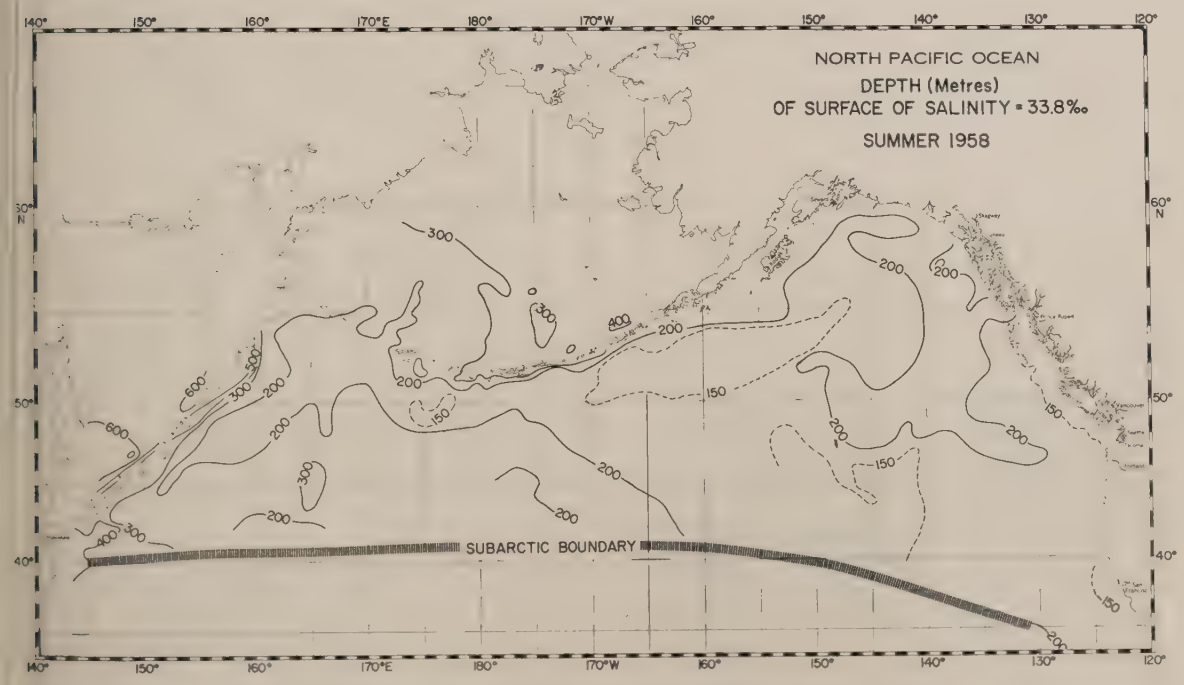


FIGURE 188. Depth (metres) of surface of salinity=33.8‰, summer 1958.

FIGURE 189. Depth (metres) of surface of salinity=33.8‰, winter 1959.

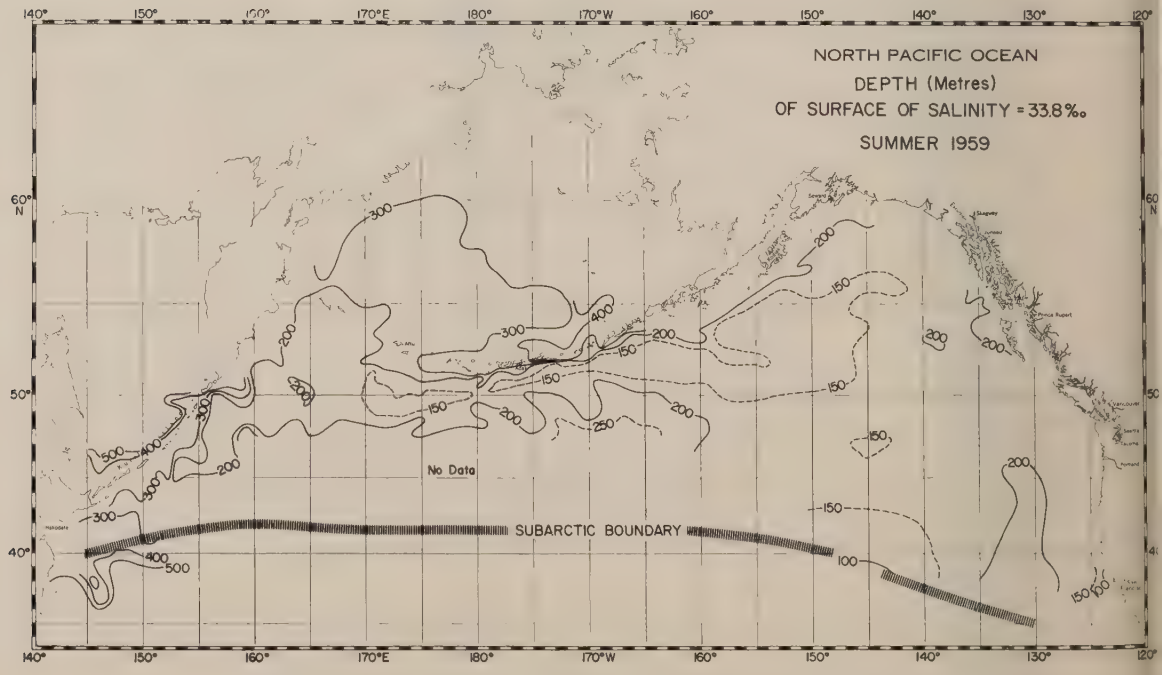


FIGURE 190. Depth (metres) of surface of salinity=33.8‰, summer 1959.

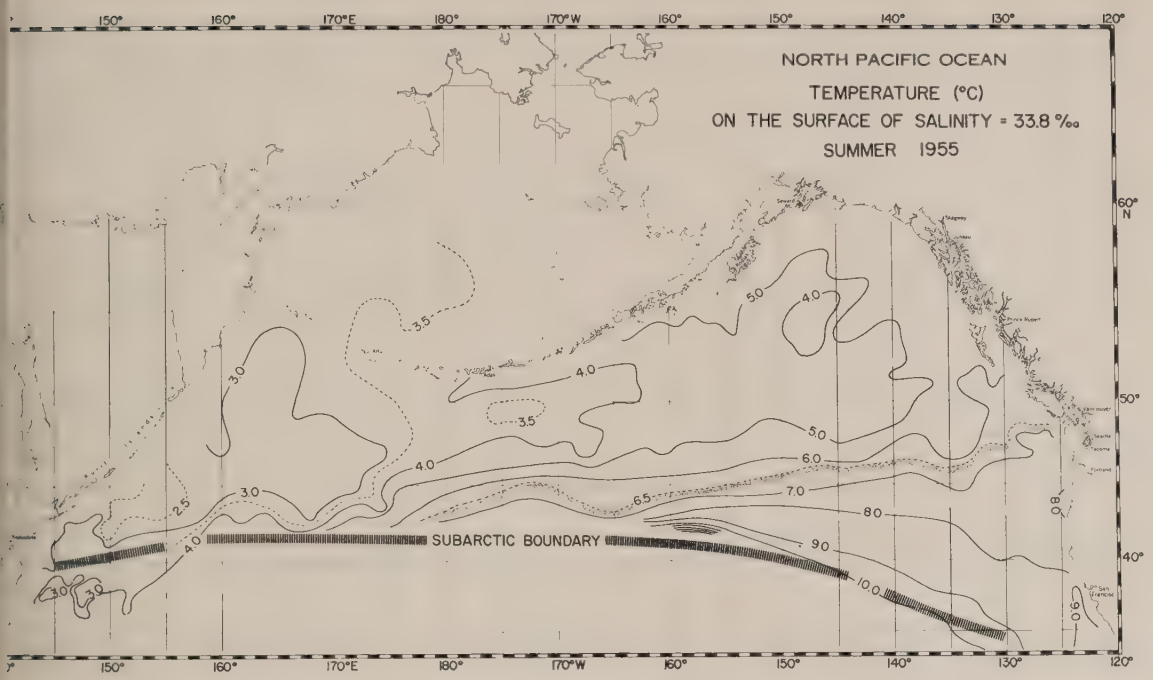


FIGURE 191. Temperature on the surface of salinity=33.8‰, summer 1955.

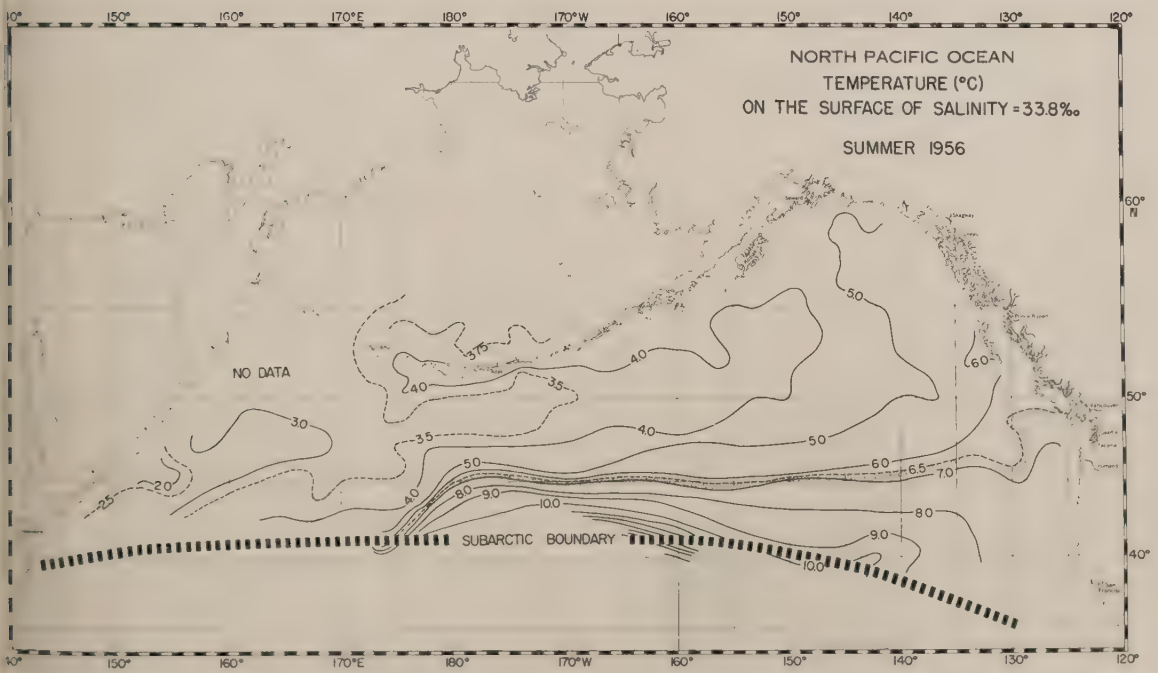


FIGURE 192. Temperature on the surface of salinity=33.8‰, summer 1956.

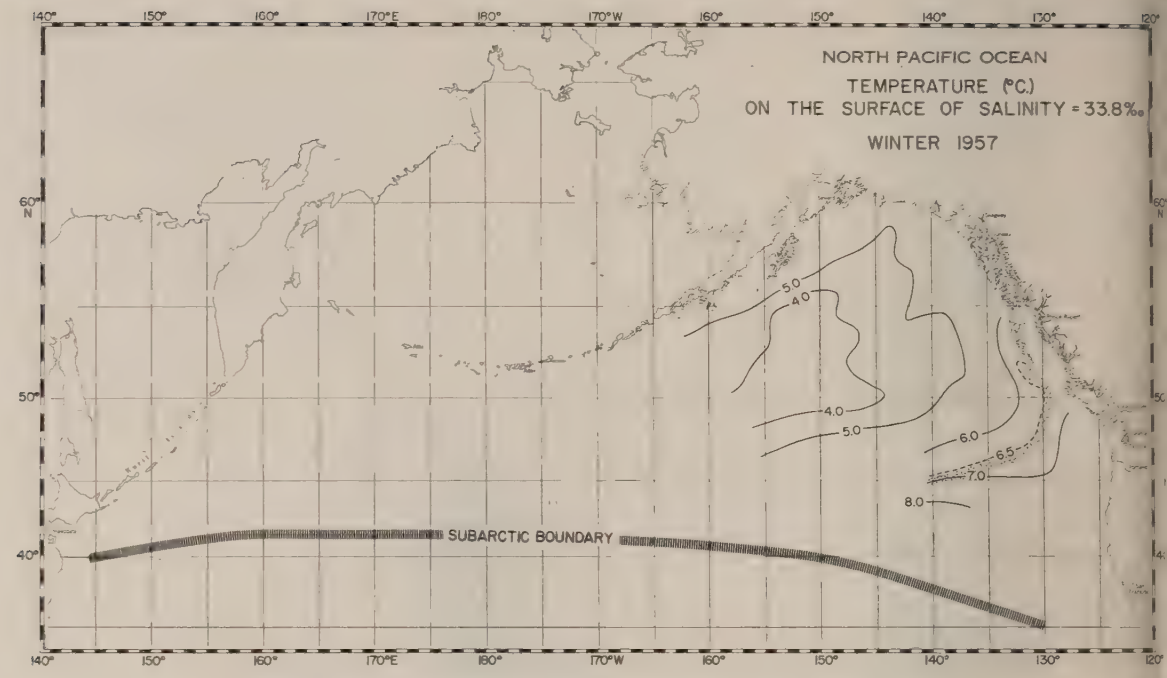


FIGURE 193. Temperature on the surface of salinity=33.8‰, winter 1957.

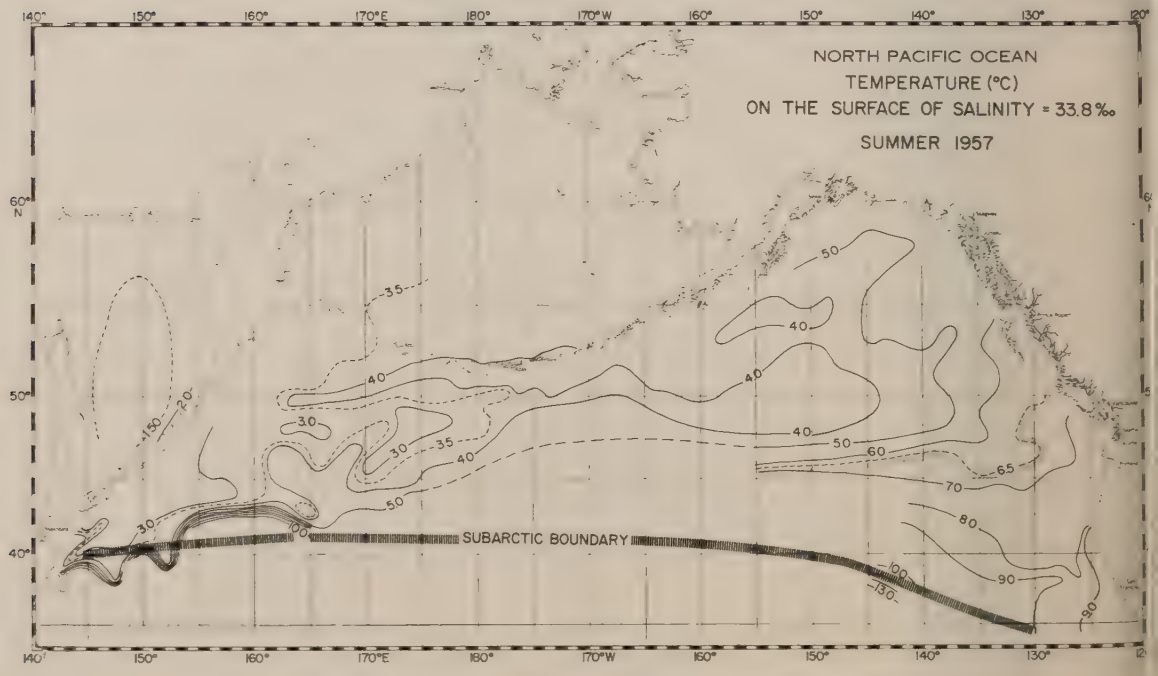


FIGURE 194. Temperature on the surface of salinity=33.8‰, summer 1957.

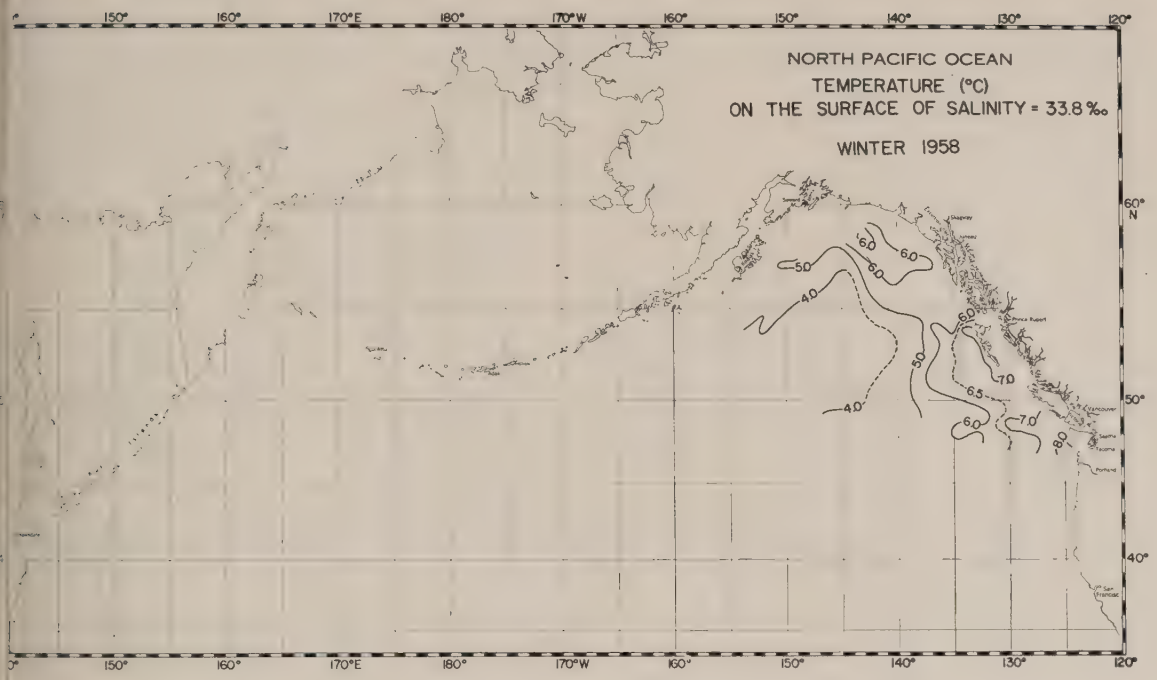


FIGURE 195. Temperature on the surface of salinity=33.8‰, winter 1958.

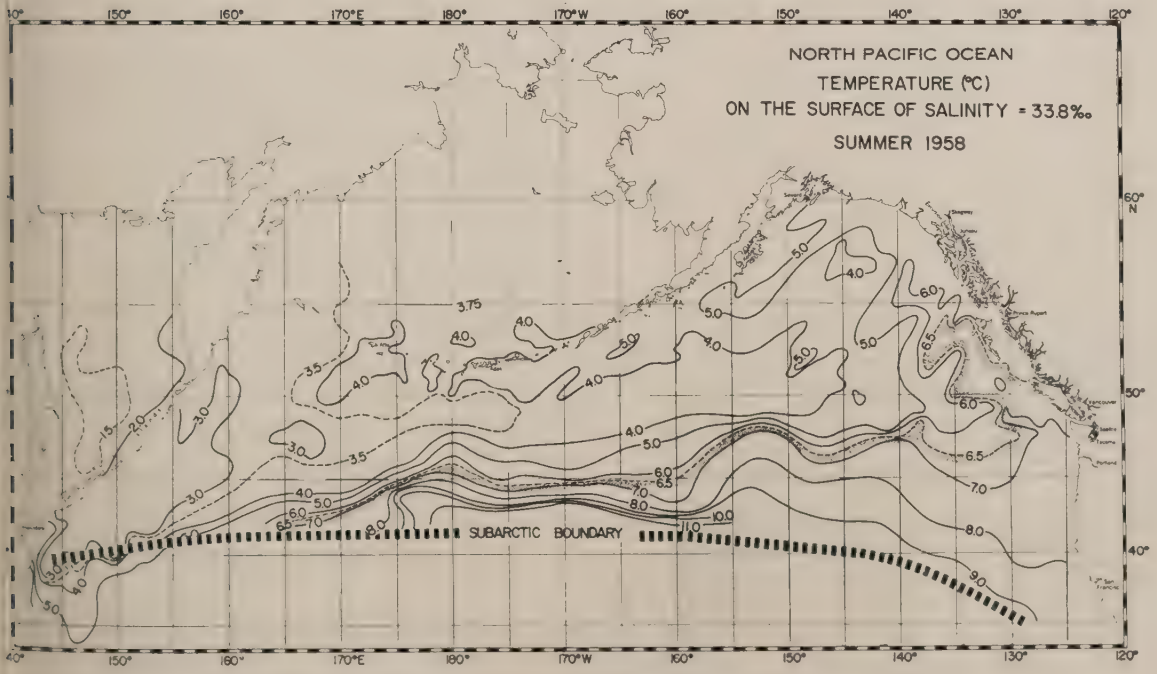


FIGURE 196. Temperature on the surface of salinity=33.8‰, summer 1958.

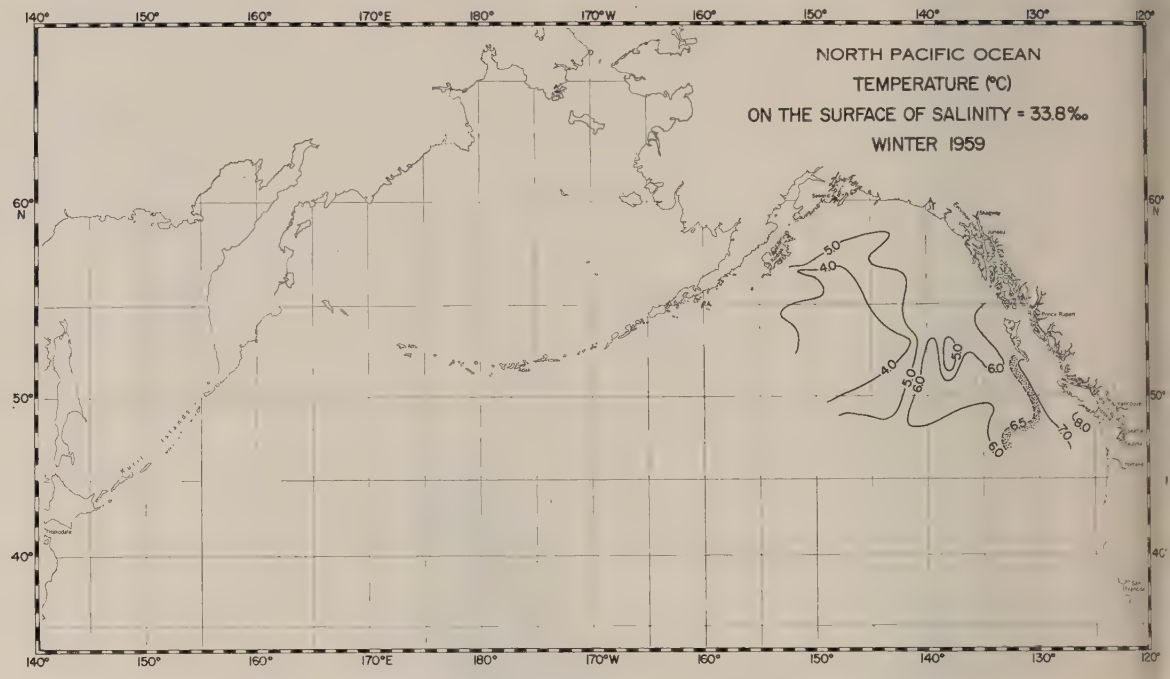


FIGURE 197. Temperature on the surface of salinity=33.8‰, winter 1959.

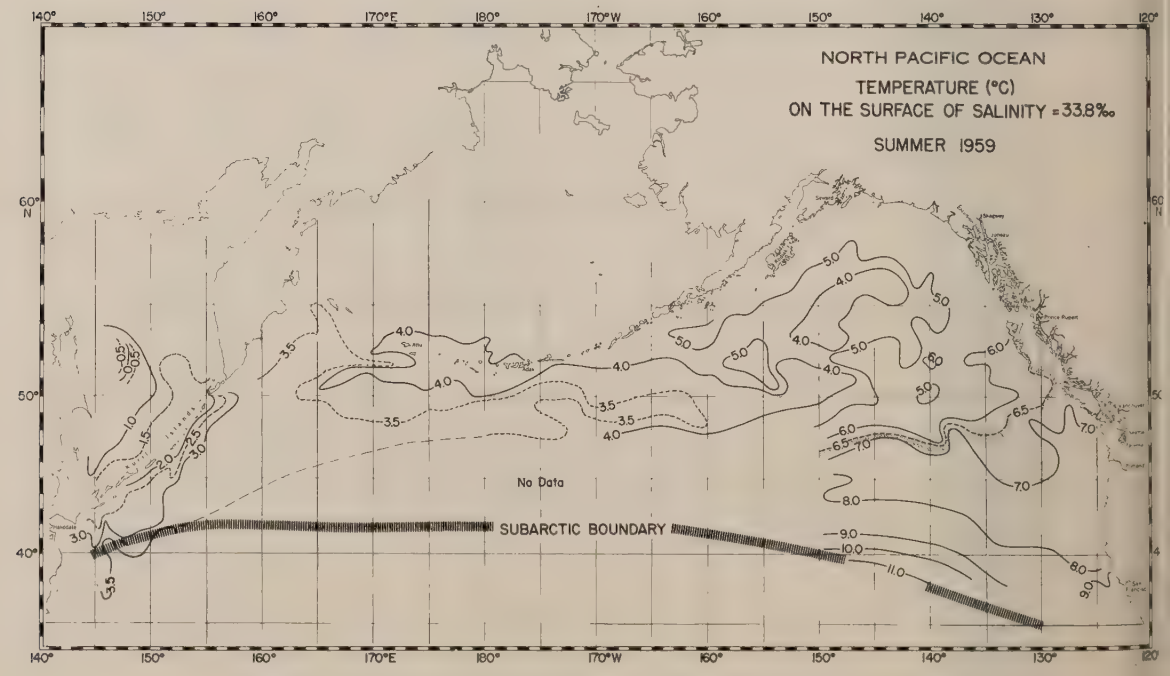


FIGURE 198. Temperature on the surface of salinity=33.8‰, summer 1959.

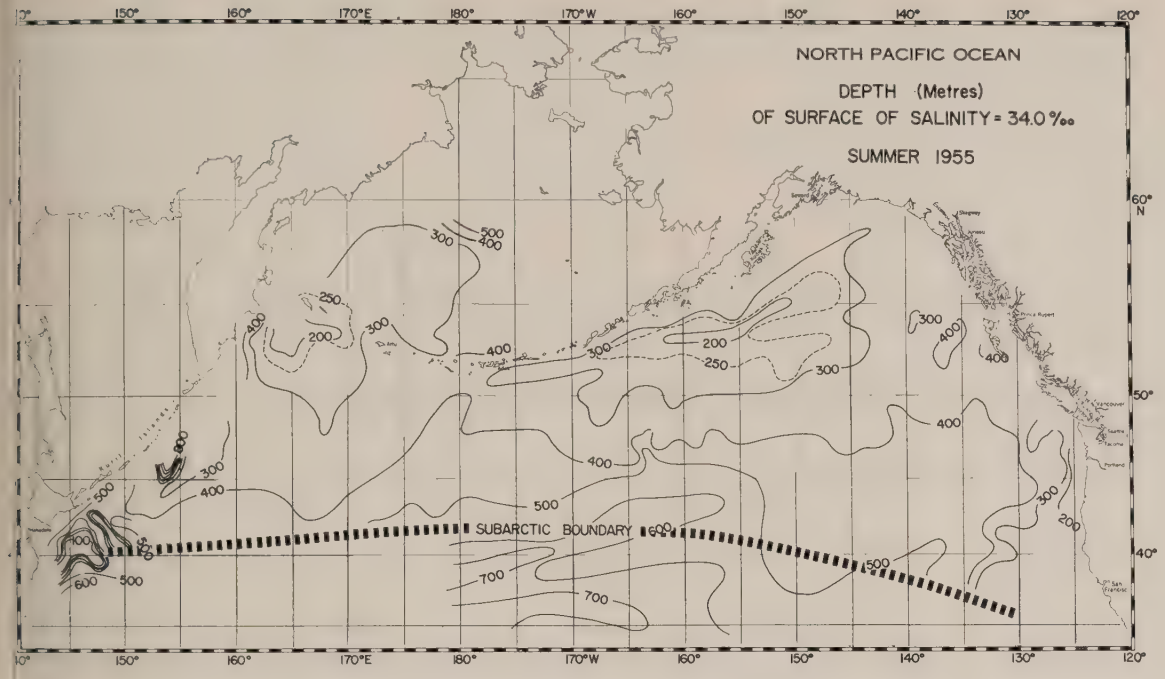


FIGURE 199. Depth (metres) of surface of salinity=34.0‰, summer 1955.

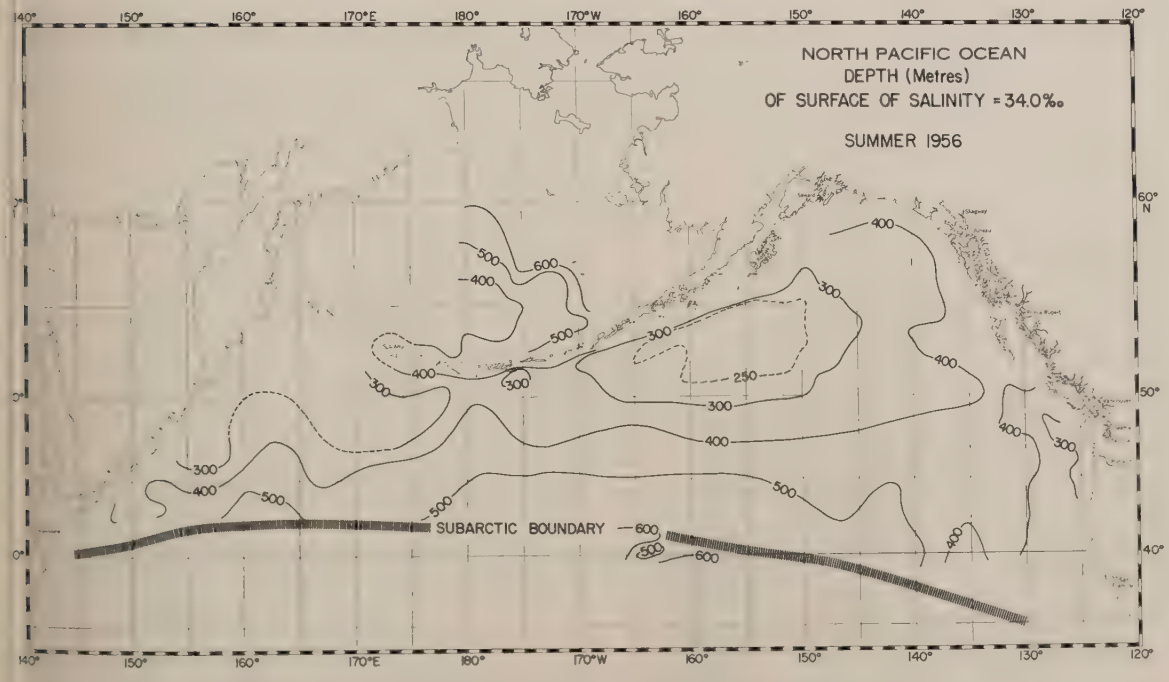


FIGURE 200. Depth (metres) of surface of salinity=34.0‰, summer 1956.

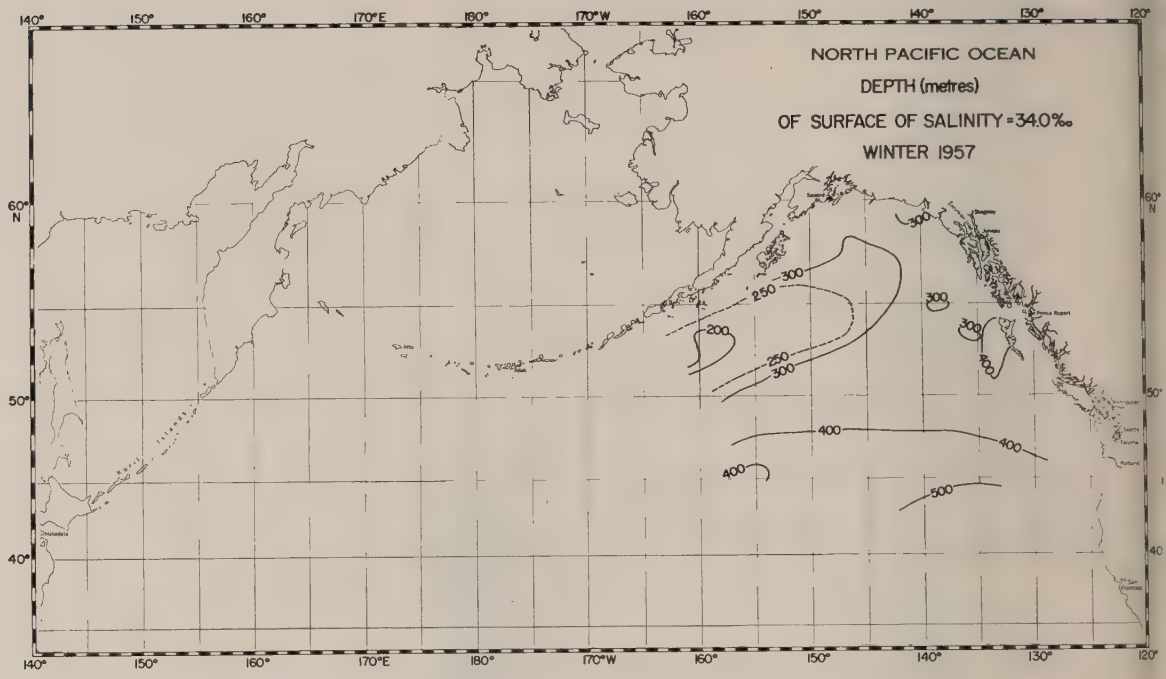


FIGURE 201. Depth (metres) of surface of salinity=34.0‰, winter 1957.

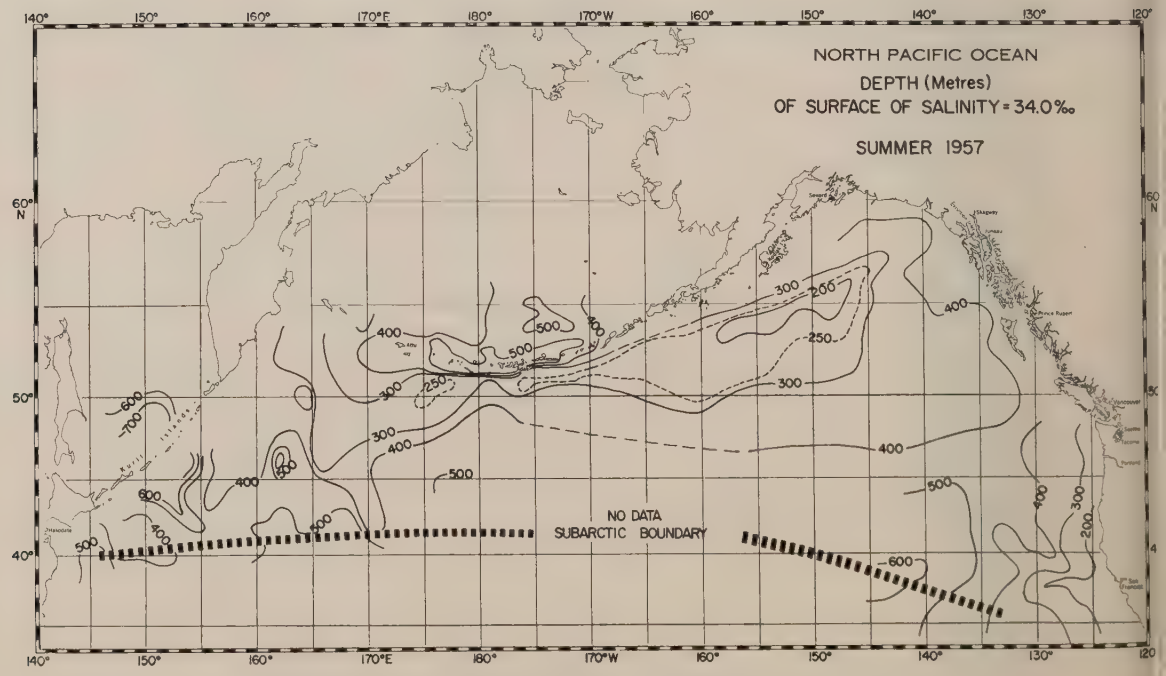


FIGURE 202. Depth (metres) of surface of salinity=34.0‰, summer 1957.

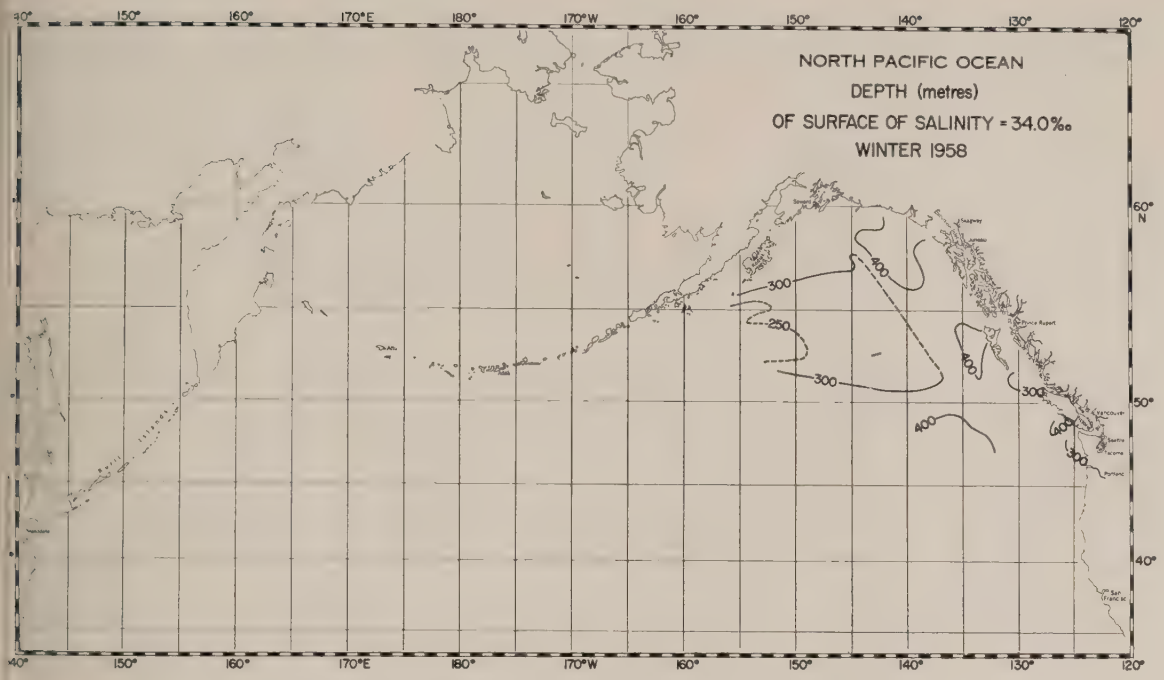


FIGURE 203. Depth (metres) of surface of salinity=34.0‰, winter 1958.

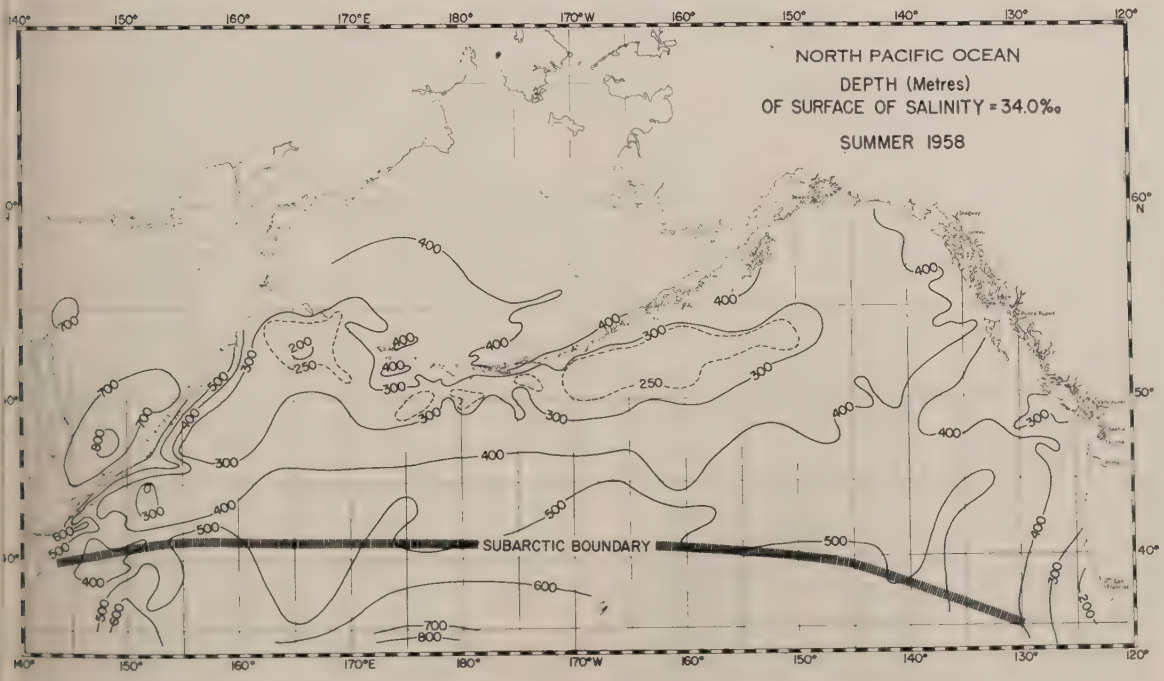


FIGURE 204. Depth (metres) of surface of salinity=34.0‰, summer 1958.

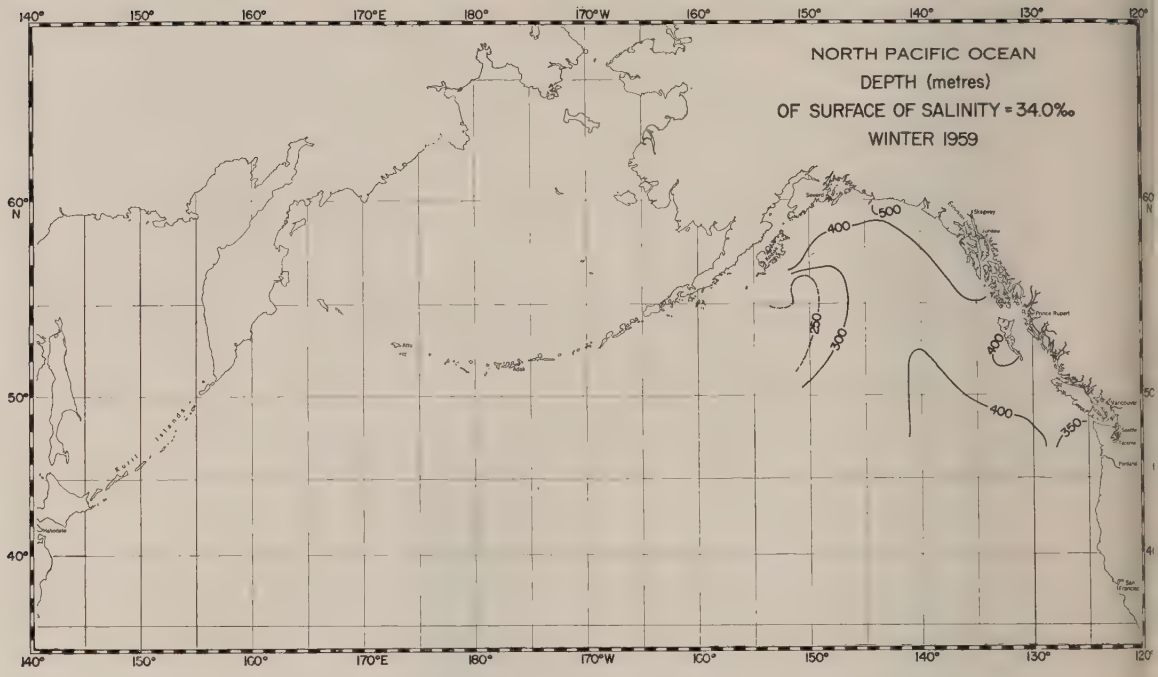


FIGURE 205. Depth (metres) of surface of salinity=34.0‰, winter 1959.

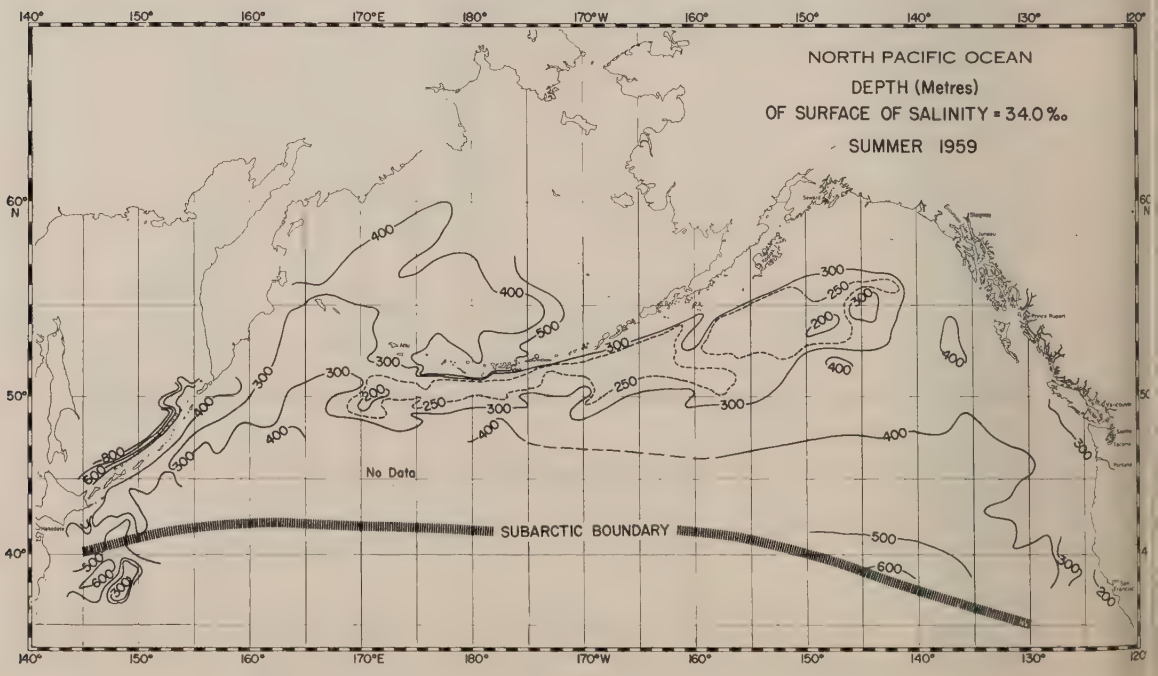


FIGURE 206. Depth (metres) of surface of salinity=34.0‰, summer 1959.

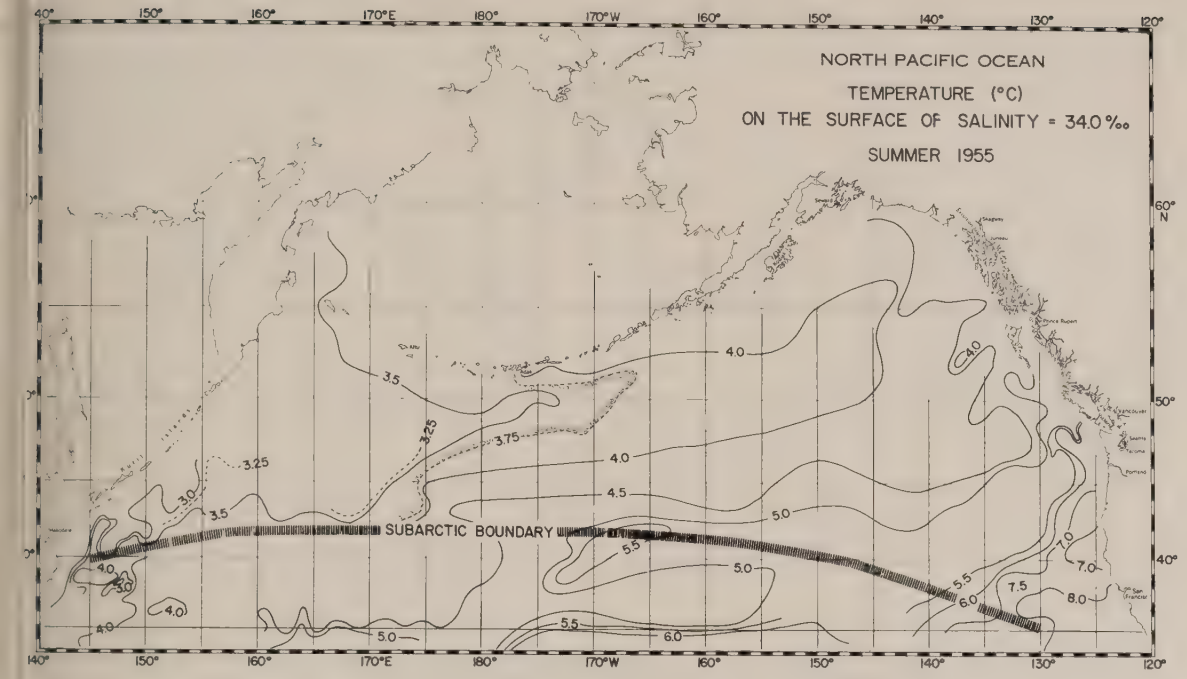


FIGURE 207. Temperature on the surface of salinity=34.0‰, summer 1955.

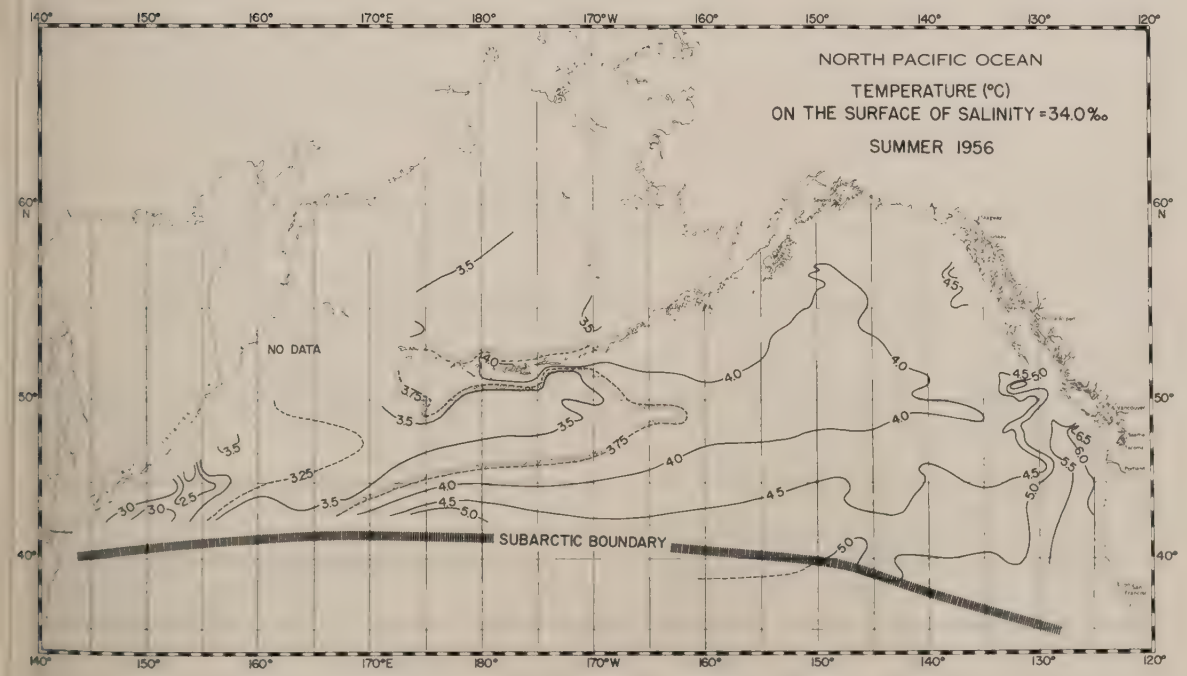


FIGURE 208. Temperature on the surface of salinity=34.0‰, summer 1956.

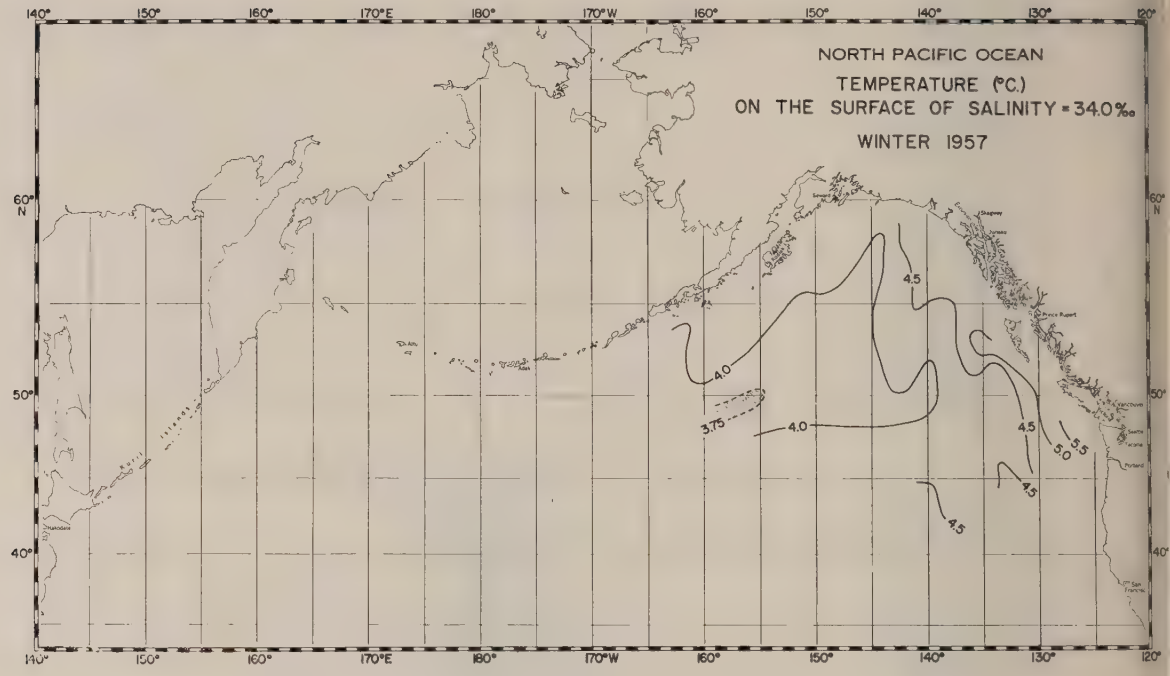


FIGURE 209. Temperature on the surface of salinity=34.0‰, winter 1957.

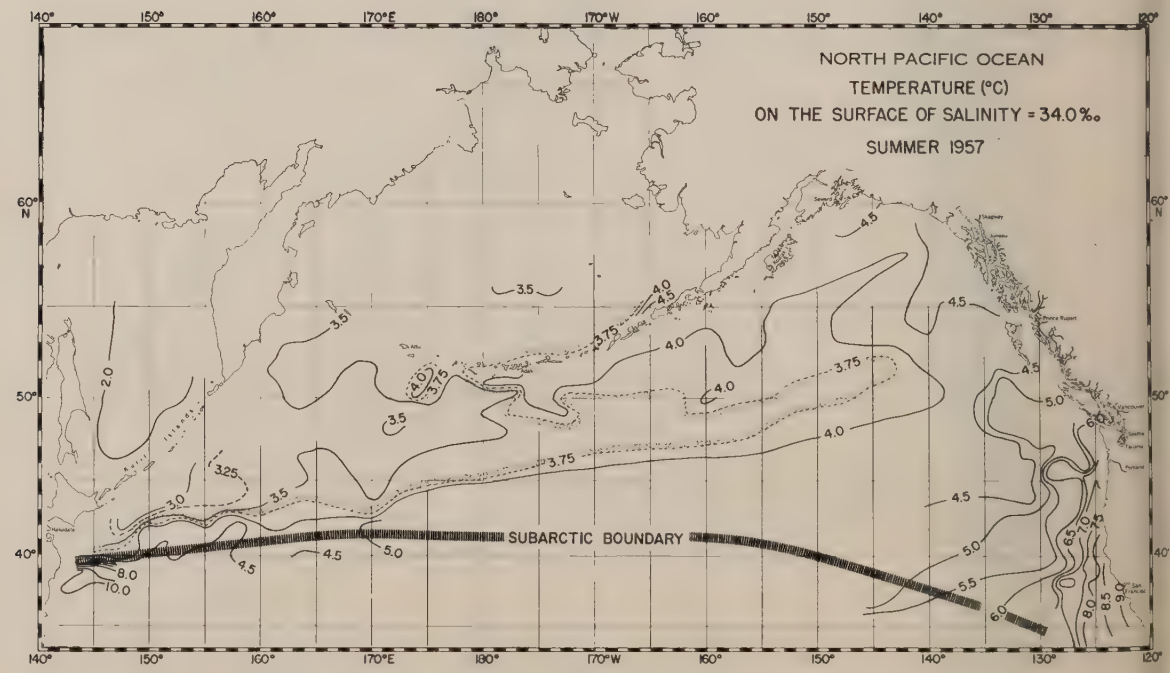


FIGURE 210. Temperature on the surface of salinity=34.0‰, summer 1957.

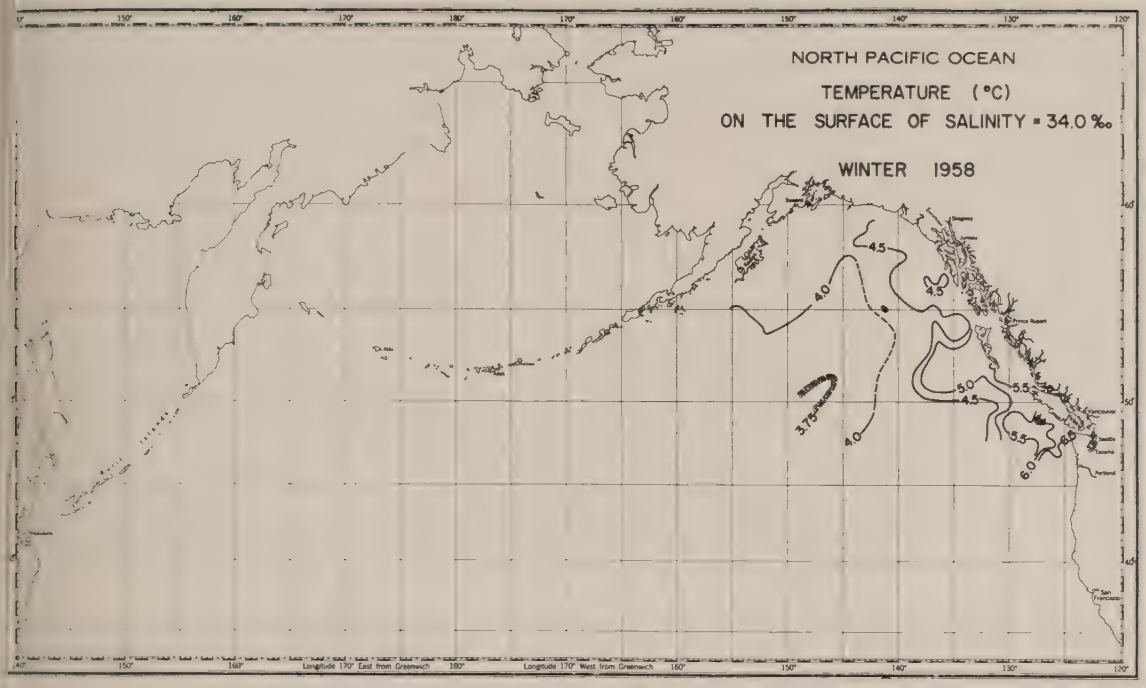

NORTH PACIFIC OCEAN
TEMPERATURE (°C)
ON THE SURFACE OF SALINITY = 34.0 ‰
WINTER 1958
Longitude 170° East from Greenwich
Longitude 170° West from Greenwich

FIGURE 211. Temperature on the surface of salinity=34.0‰, winter 1958.

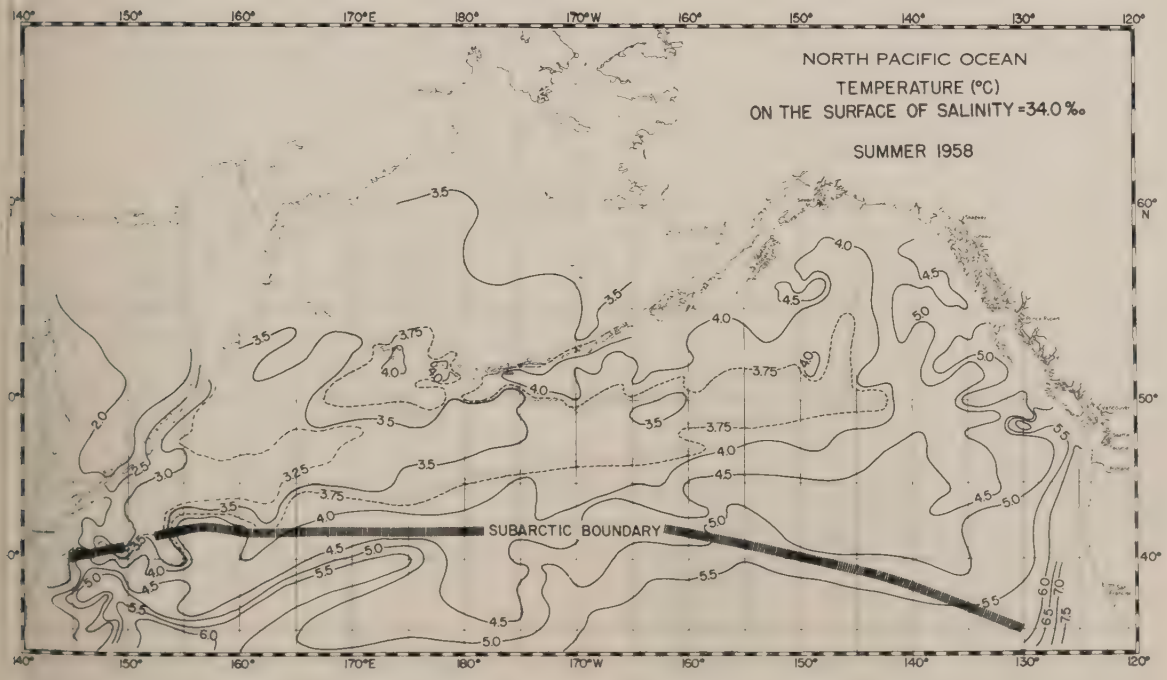


FIGURE 212. Temperature on the surface of salinity=34.0‰, summer 1958.

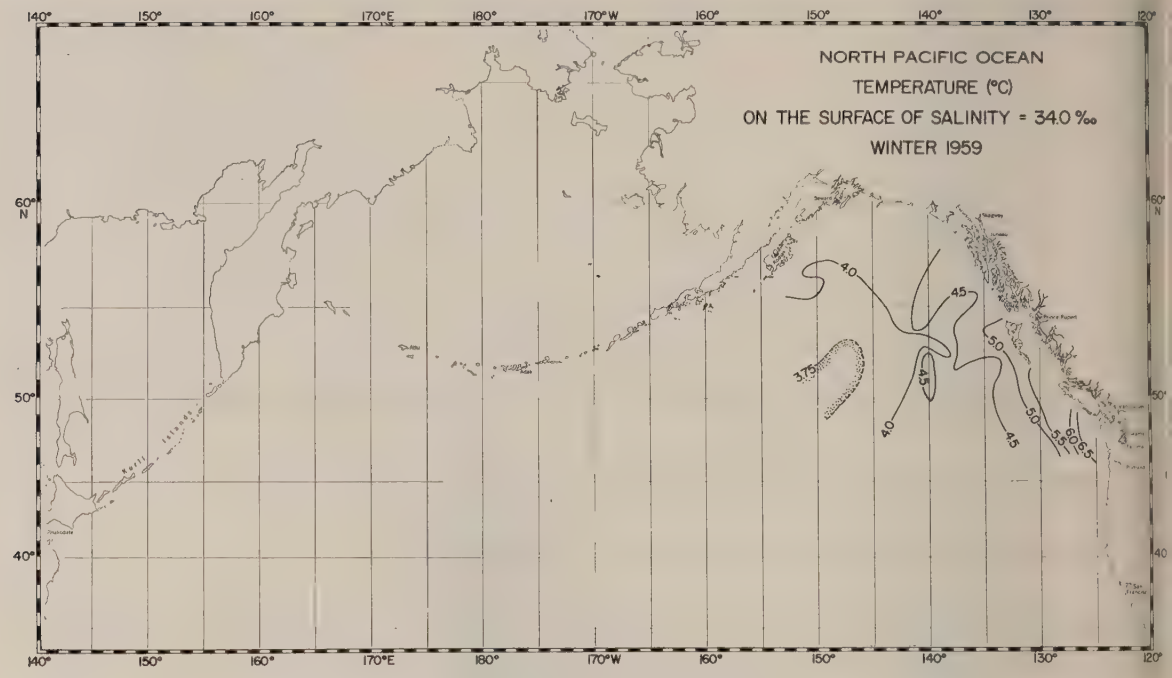


FIGURE 213. Temperature on the surface of salinity=34.0‰, winter 1959.

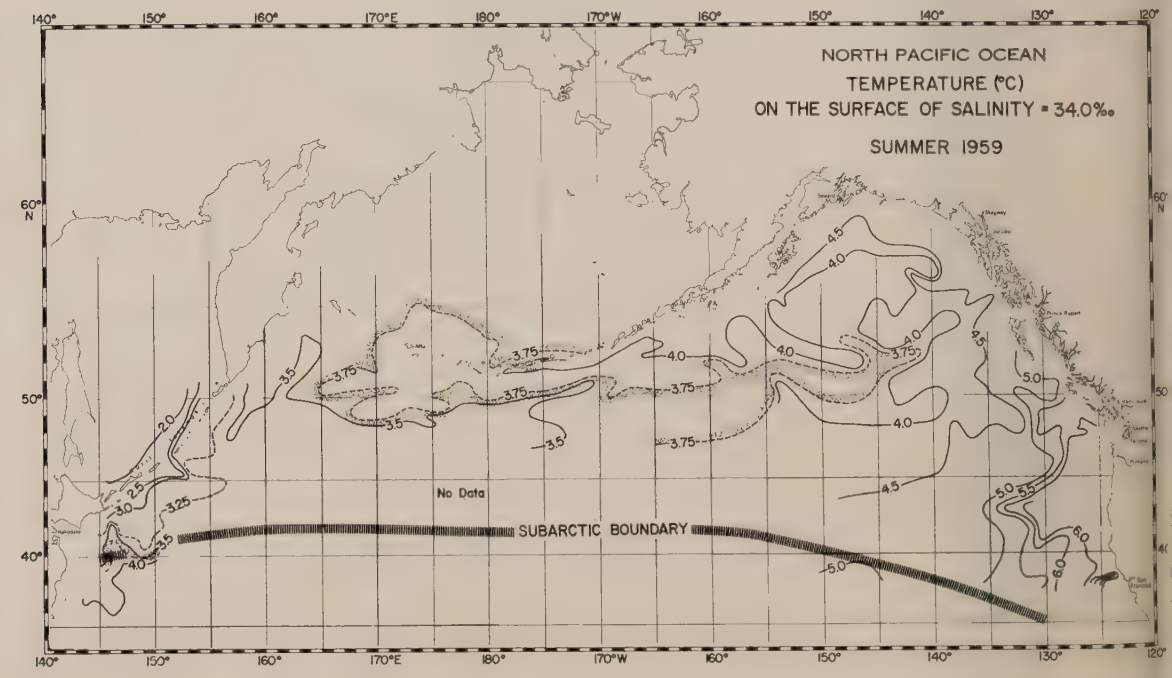


FIGURE 214. Temperature on the surface of salinity=34.0‰, summer 1959.

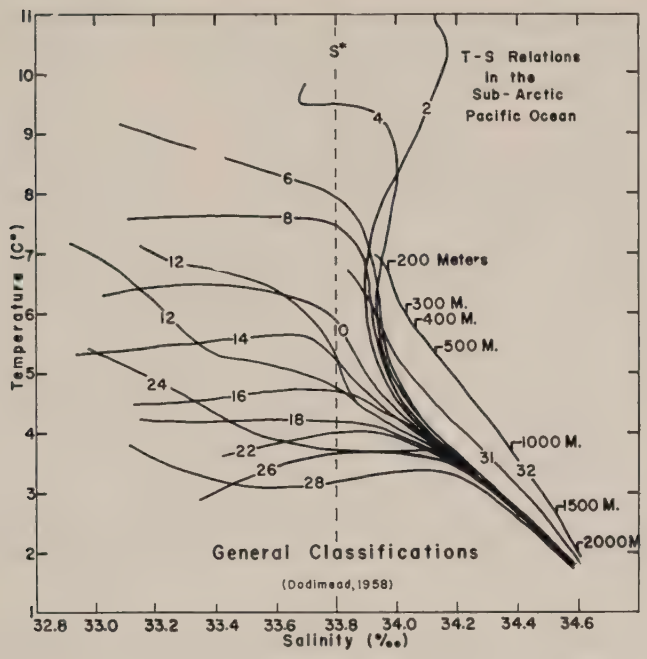


FIGURE 215. Temperature-salinity curves (Dodimead, 1958).

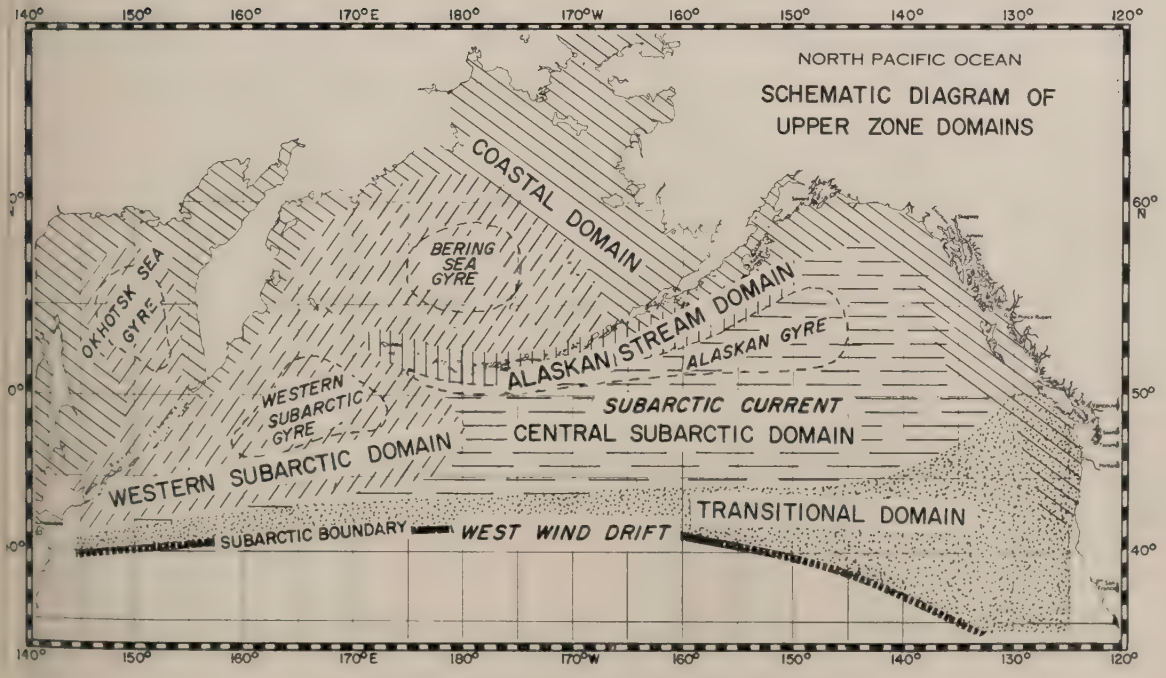


FIGURE 216. Schematic diagram of upper zone domains.

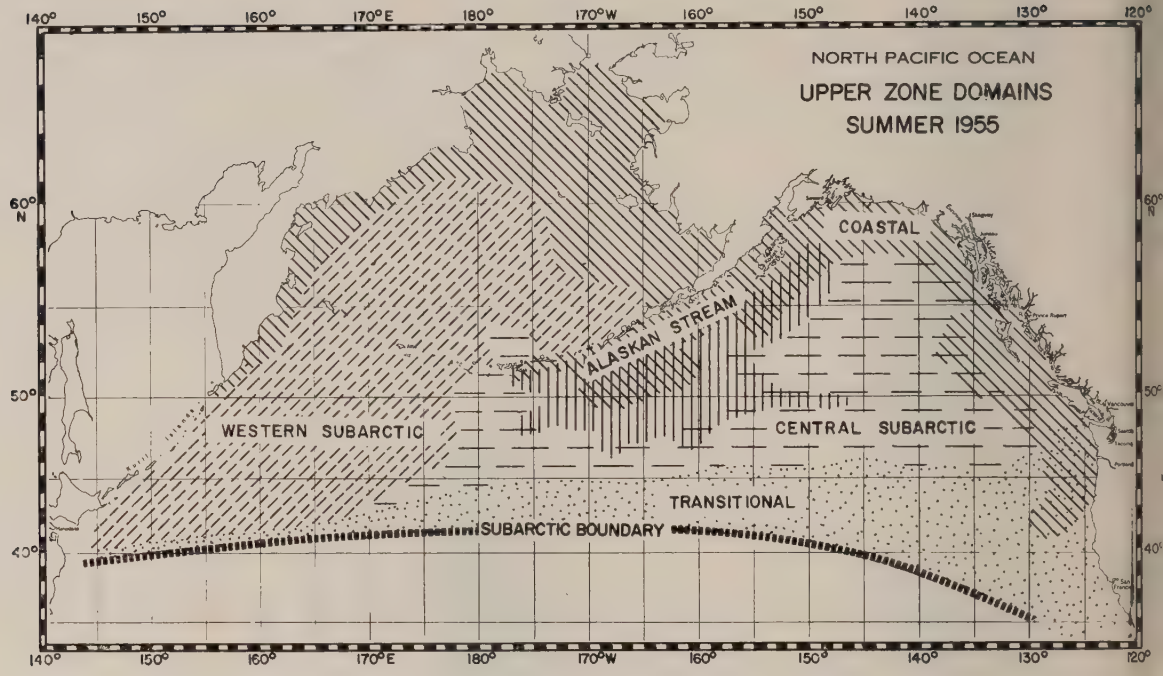


FIGURE 217. Upper zone domains, summer 1955.

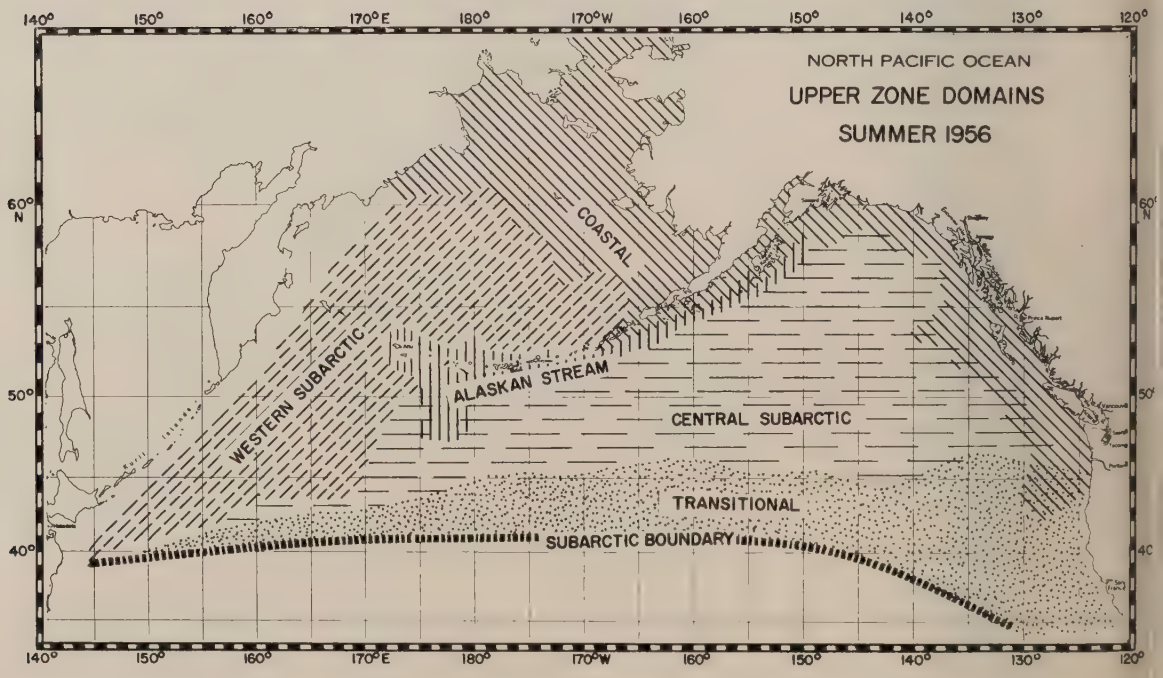


FIGURE 218. Upper zone domains, summer 1956.

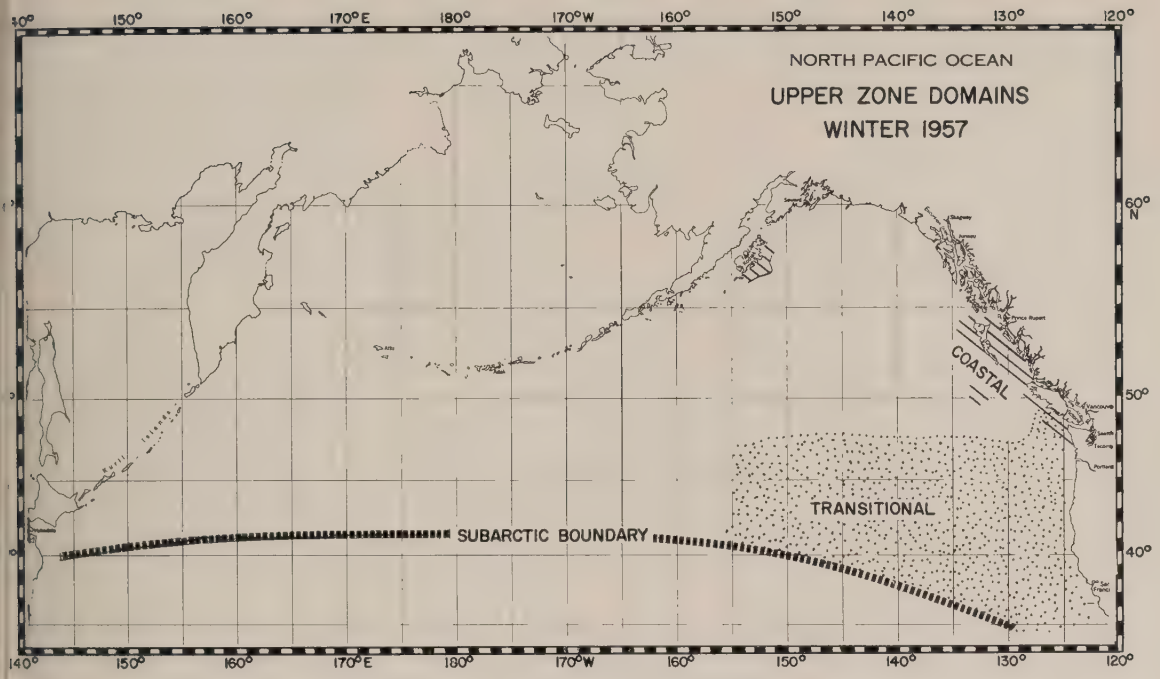


FIGURE 219. Upper zone domains, winter 1957.

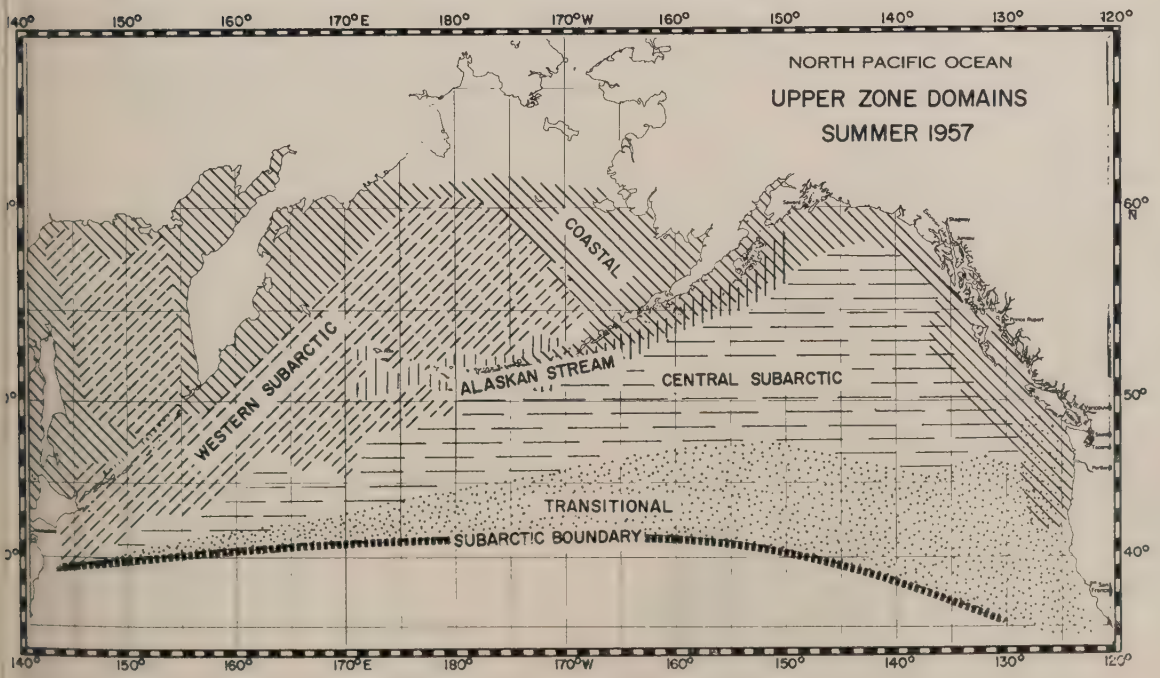


FIGURE 220. Upper zone domains, summer 1957.

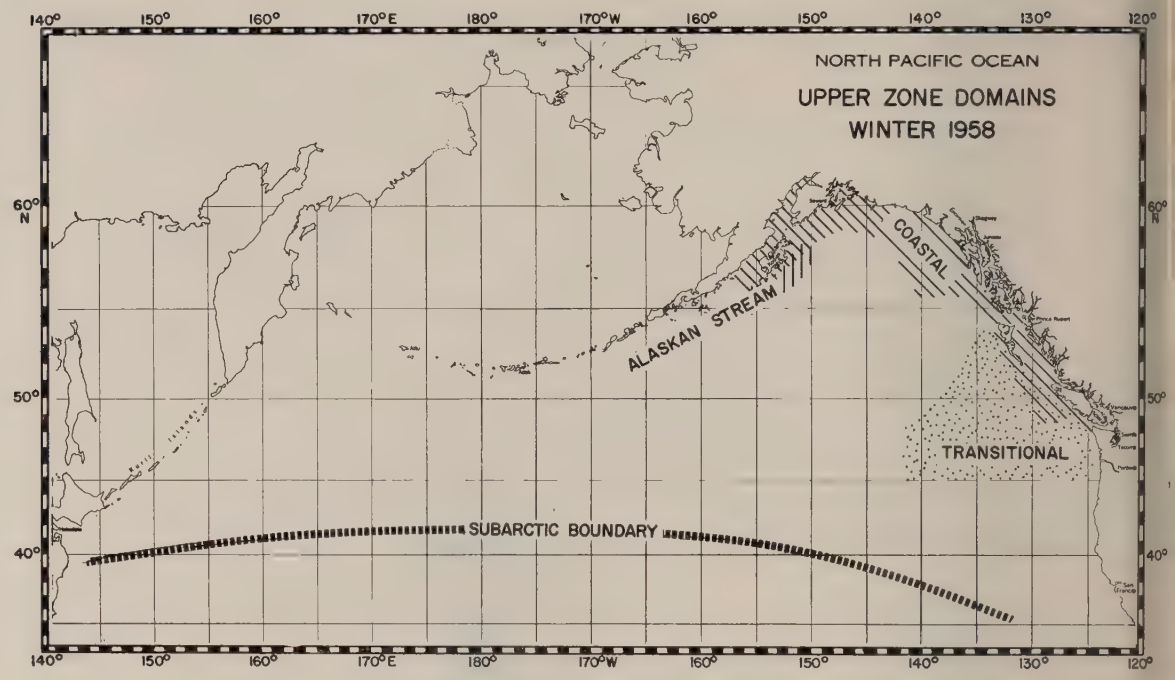


FIGURE 221. Upper zone domains, winter 1958.

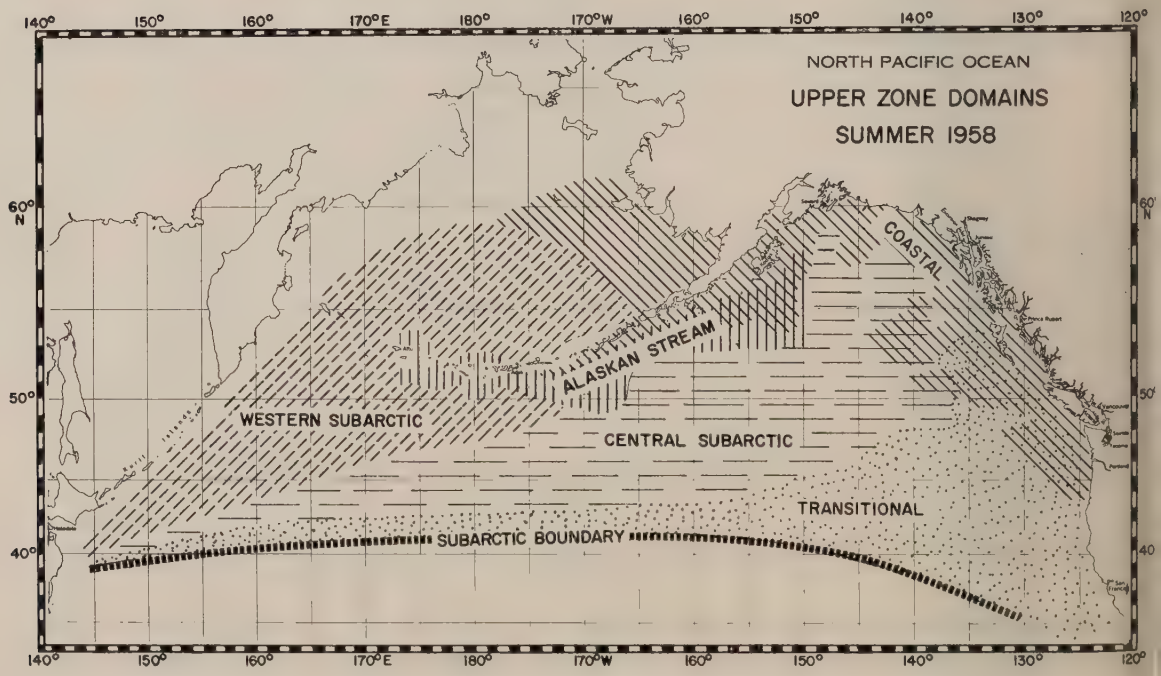


FIGURE 222. Upper zone domains, summer 1958.

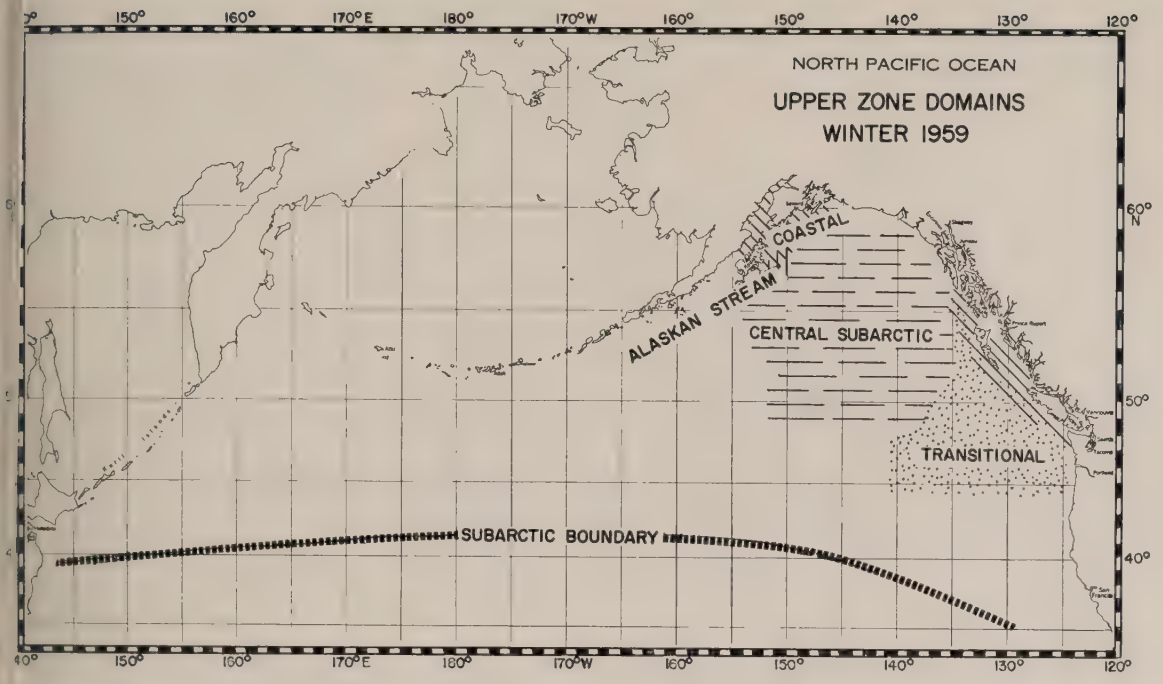


FIGURE 223. Upper zone domains, winter 1959.

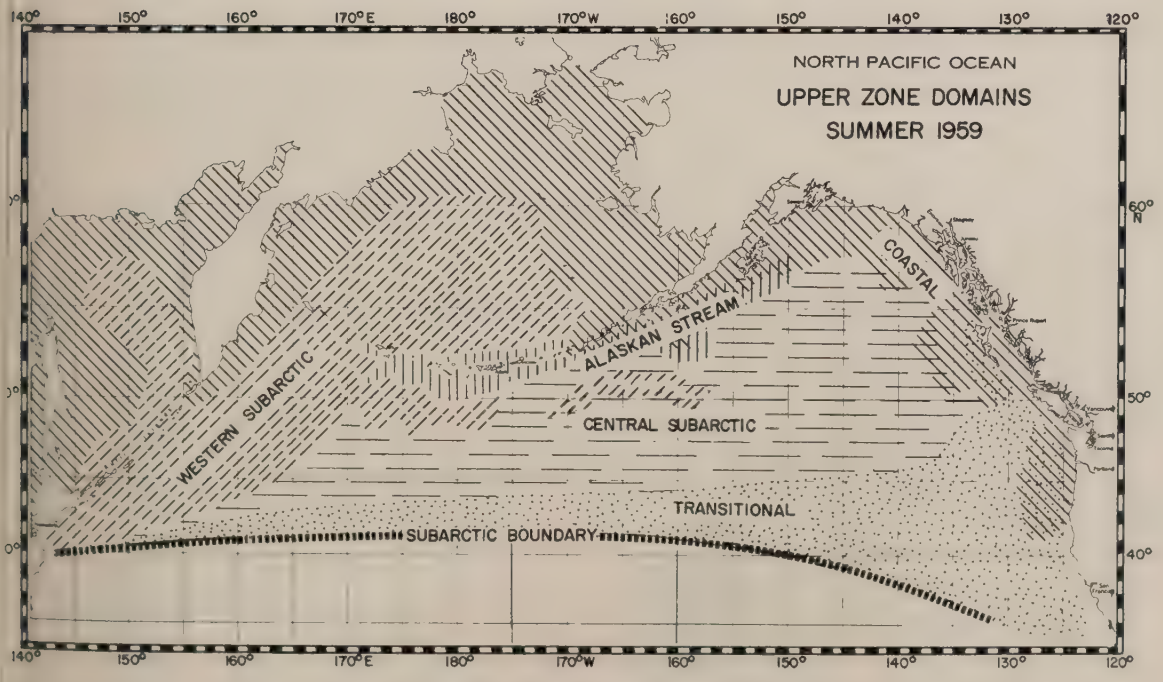


FIGURE 224. Upper zone domains, summer 1959.

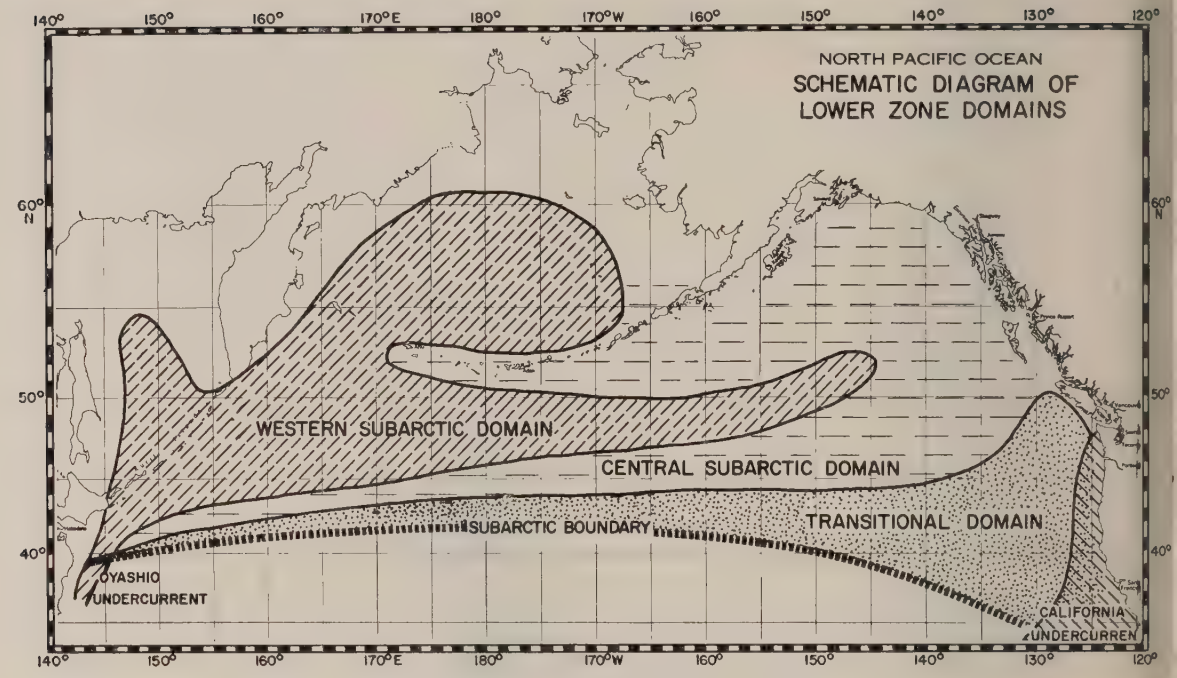


FIGURE 225. Schematic diagram of lower zone domains.

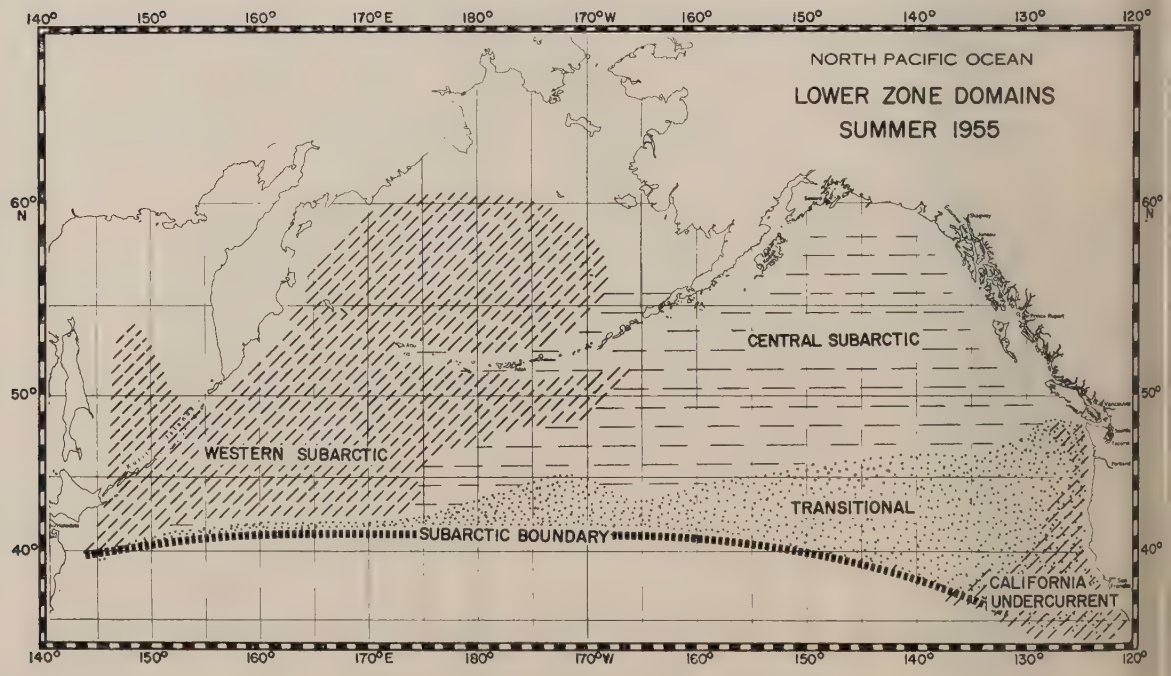


FIGURE 226. Lower zone domains, summer 1955.

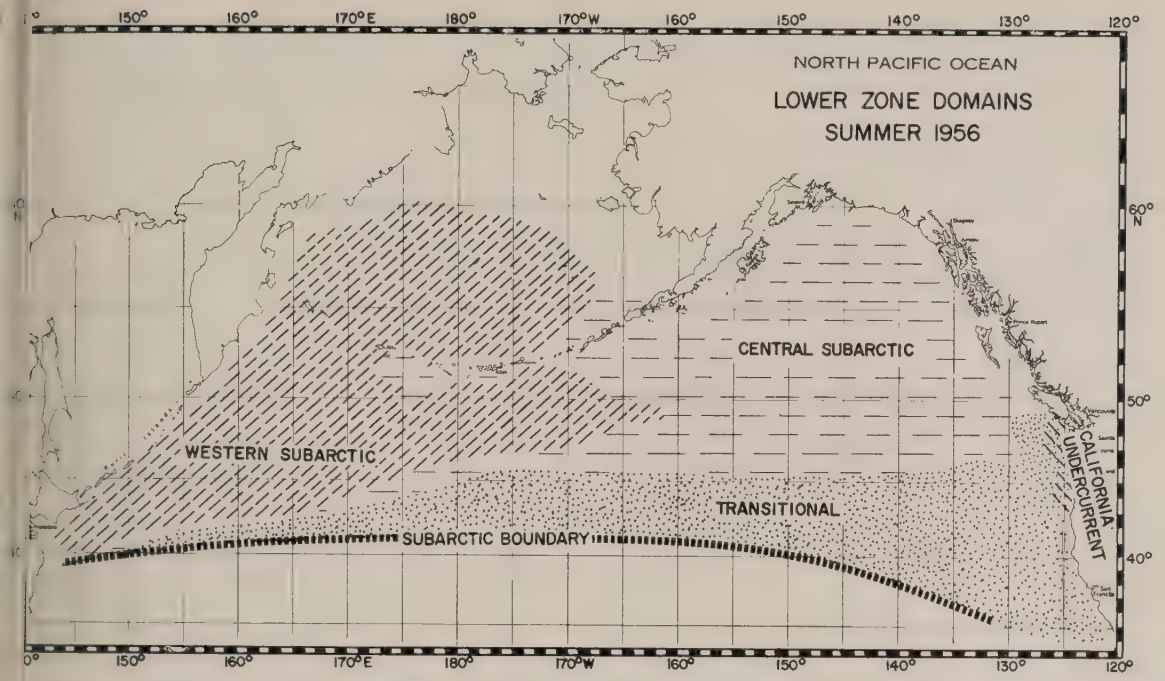


FIGURE 227. Lower zone domains, summer 1956.

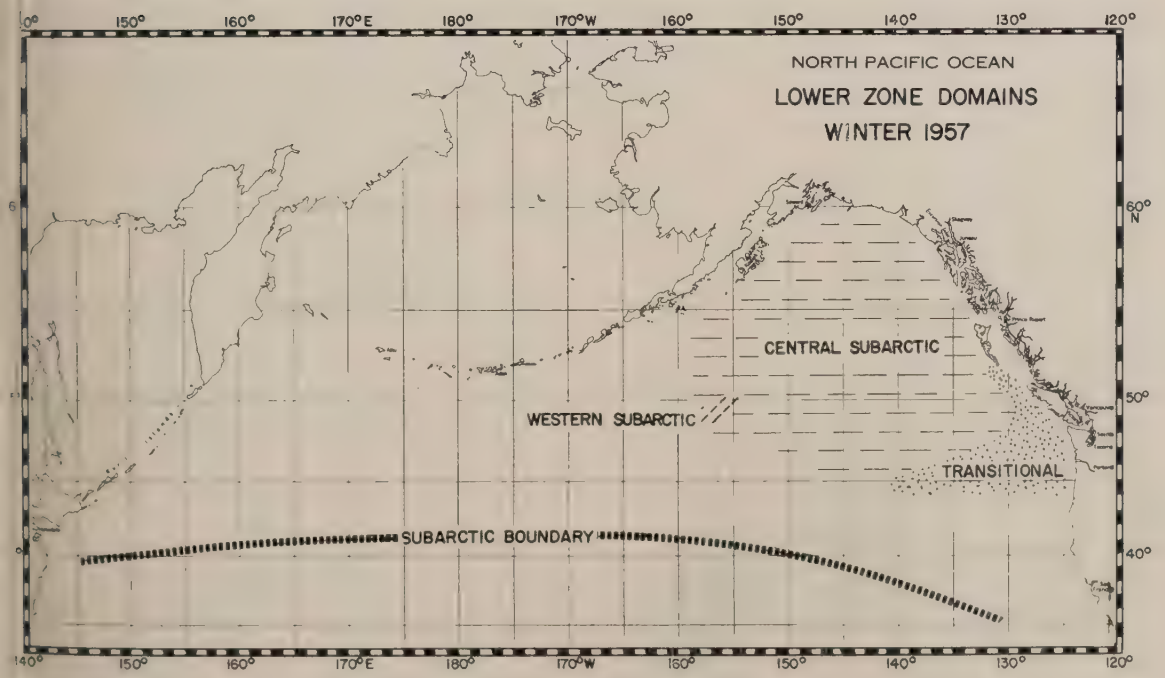


FIGURE 228. Lower zone domains, winter 1957.

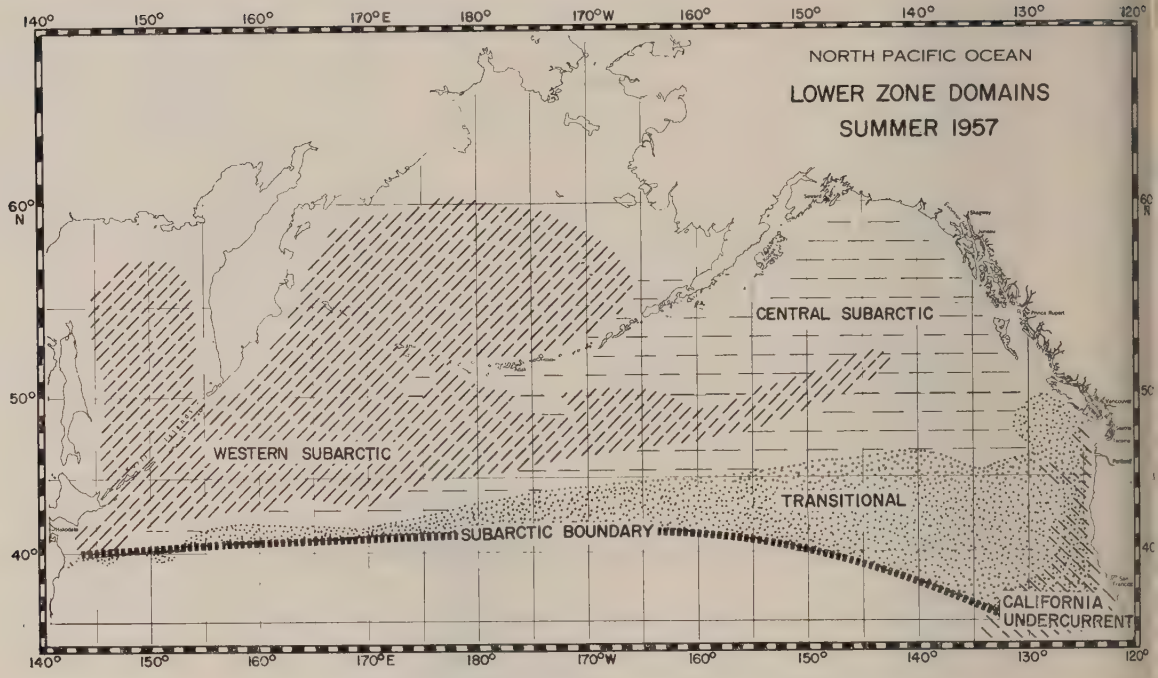


FIGURE 229. Lower zone domains, summer 1957.

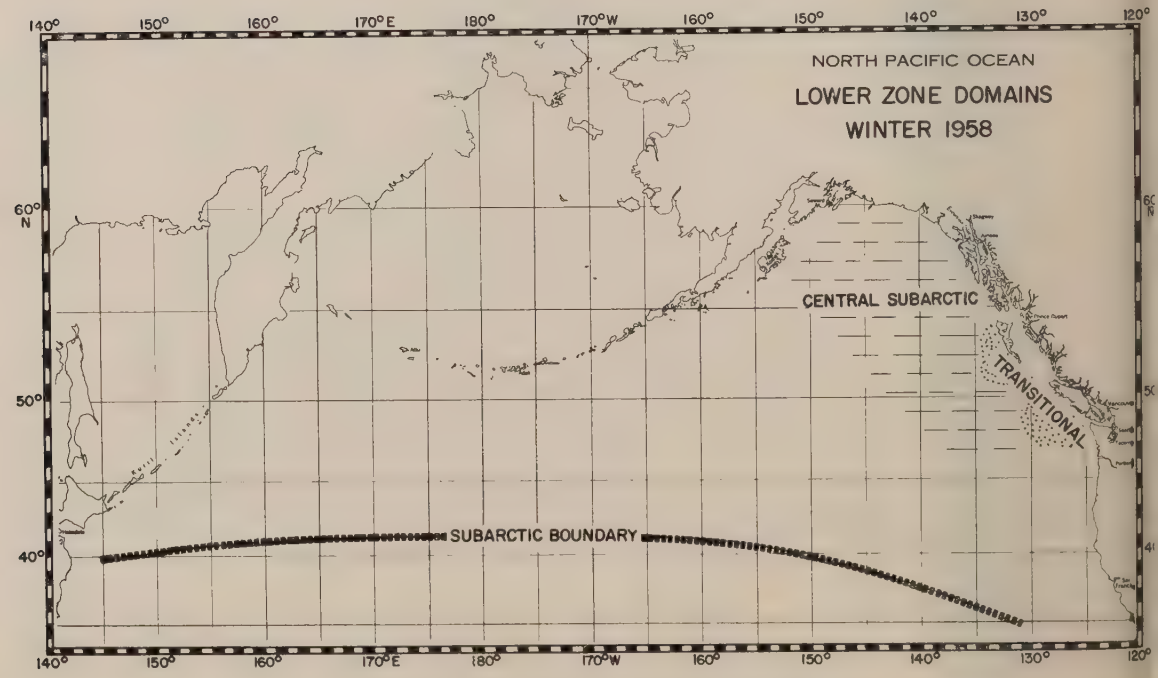


FIGURE 230. Lower zone domains, winter 1958.

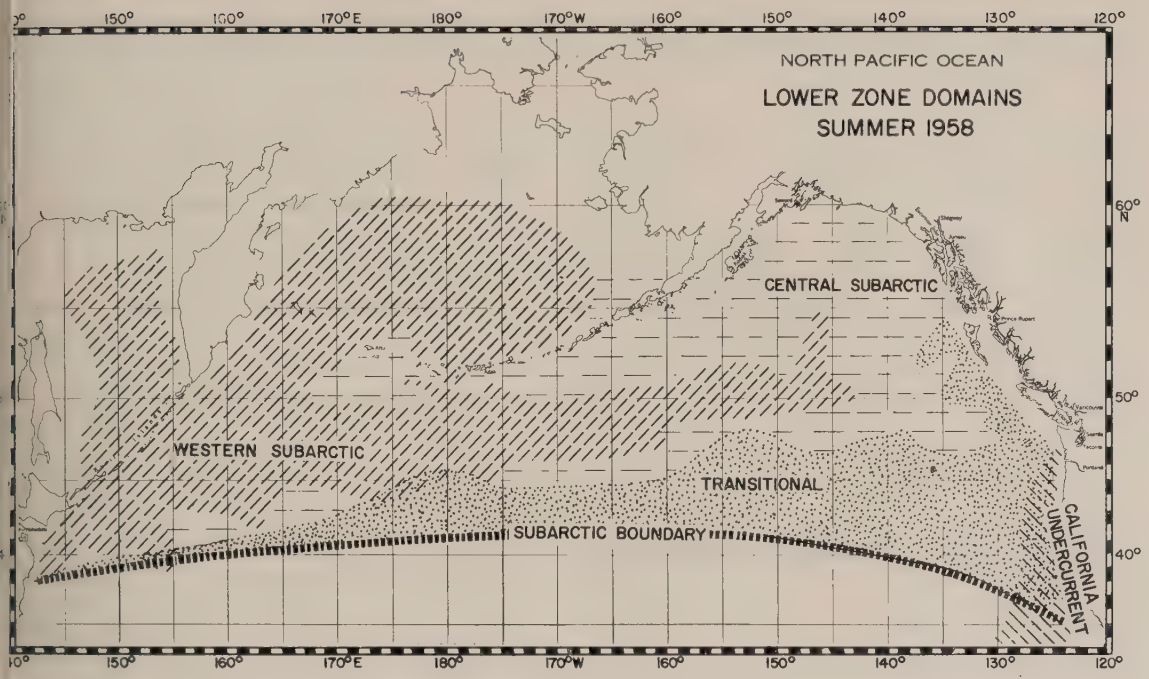


FIGURE 231. Lower zone domains, summer 1958.

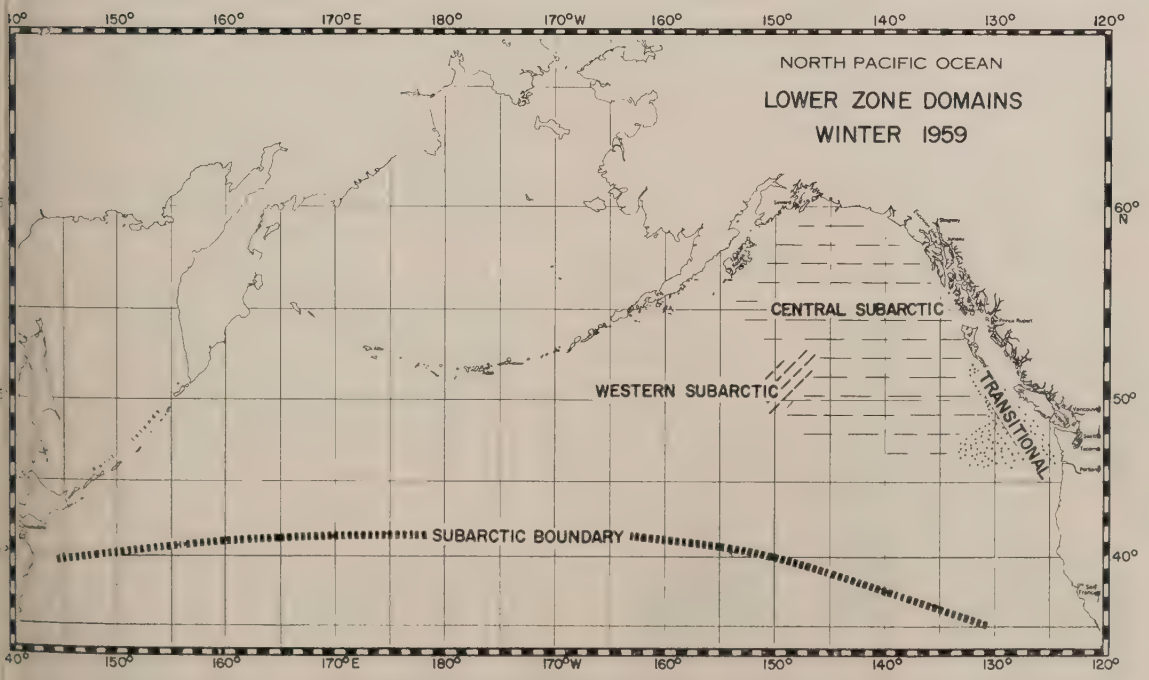


FIGURE 232. Lower zone domains, winter 1959.

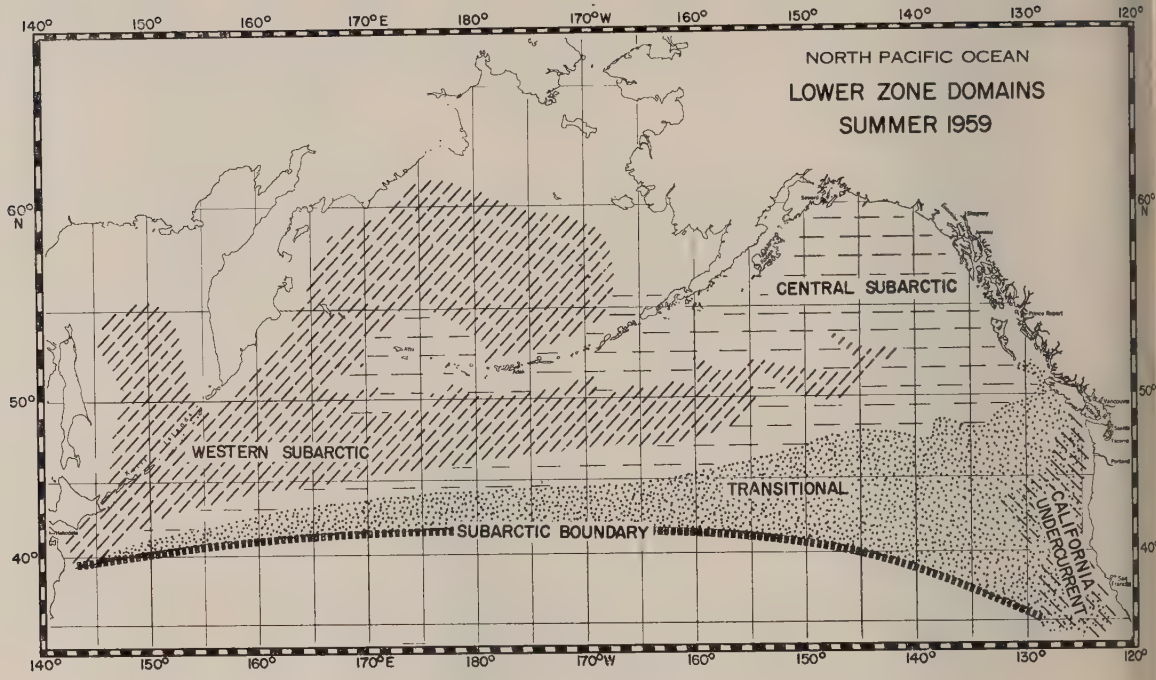


FIGURE 233. Lower zone domains, summer 1959.

APPENDIX I: OCEANOGRAPHY OF BRISTOL BAY

Description of Area

Bristol Bay is that part of the Bering Sea eastward of a line drawn from Cape Sarichef to the Kuskokwim River (App. I Fig. 1). It is the southeastern terminus of the shallow continental shelf in the Bering Sea, and is separated from the North Pacific Ocean by the Alaska Peninsula.

According to the U.S. Coast Pilot (1954) the annual mean air temperature is approximately 35°F. and the annual rainfall 30 to 40 inches; fog occurs during every month of the year. Depending on the severity of the winter temperatures, ice begins to form along the shore in October or November, grows until March and melts by April. Solid fields of drift ice have been reported offshore in the Bay as late as May.

Although the shores of the Bay are low, the encircling mountains form a large watershed area. In spring, after the ice breaks up in the rivers, snowmelt and runoff enter the Bay through numerous river systems such as the Kuskokwim, Nushagak, Kvichak, Naknek, Egegik, Ugashik and others. The extensive runoff during spring and summer and the presence of ice during winter result in a considerable range of oceanographic conditions in the shallow Bay.

The movement of water in the Bay is affected by runoff, ice, prevailing winds, tidal currents, and the movement of oceanic water off the continental shelf. Winds are usually from a northerly direction in late autumn and during winter, and shift to a southerly direction in late spring. The range of tide at the Naknek River entrance is about 24 feet and results in tidal currents in excess of three knots. This is contrasted with a tidal range of about three feet at the Pribilof Islands.

The Bay is of particular interest oceanographically because, as shown by recent drift bottle experiments, drifting objects enter the Bay from the extreme western Aleutians, the Gulf of Alaska, and as far south as lat. 48° N. in the central Subarctic (App. I Fig. 2). However, none have been recovered in the headwaters of the Bay.

Previous Oceanographic Investigations

The work of Saur *et al.* (1952) discussed earlier (p. 7) included a summary of cruises conducted in the Bering Sea. Omitted from this summary were cruises by the Japanese Fisheries Training School vessel *Hakuho Maru* during 1930 and 1933 to 1936, and the U.S.C.G.T. *Redwing* during 1938 to 1941.

Since 1956 oceanographic data have been obtained in Bristol Bay from vessels chartered by the U.S. Bureau of Commercial Fisheries in conjunction with crab investigations. Most of these data are not published.

Hebard (1959) obtained direct-current measurements at four locations in the Bay during June 1957 and ascertained the presence of rotary (although elongated in northeast and southwest direction) tidal currents. Velocities of 0.1 to 1.7 knots were observed with little difference between the direction of flow at the surface and the bottom. A net or average flow of less than 0.1 knot in a counterclockwise direction was deduced.

An oceanographic survey in the Bering Sea during winter 1955 (U. S. Navy Hydrographic Office, 1958) greatly contributed to an understanding of oceanographic conditions on the continental shelf. It was known that during the winter most of the shelf area is covered with sea ice, and one was temped to speculate that the freezing-out process would result in the formation of cold, very saline water. This would result in very dense, bottom water that would flow off the continental shelf seeking a lower level of equivalent density. The 1955 data showed that in the Bristol Bay area the water column was isothermal with temperatures of −0.5°C. to −1.5°C. (App. I Fig. 3) and isohaline with salinities of 31.5‰ to 31.8‰ (App. I Fig. 4). Similar temperatures and salinities have been found on the shelf at depths from 50 to 100 metres during spring and early summer. Hence, this water is not dense enough to form intermediate or bottom water in the Bering Sea.

Oceanographic Investigations, U.S.C.G.T. *Redwing*

These surveys during 1938 to 1941 are by far the most extensive and complete ever obtained in Bristol Bay. The work was terminated by World War II and since there is no record of prior analysis of these data, they are used to a great extent in this report to define conditions in the Bay. This is justified by the fact that conditions (temperature and salinity) have not appreciably changed from that period to the present day. Recent oceanographic coverage is not adequate to show a comparison of specific properties at specific depths; however, comparison of average monthly air temperatures for 1939 and 1959 at Dillingham (located near the head of the Bay) (shown in App. I Fig. 5) provides convincing evidence that

the climate has been relatively stable.

The *Redwing* investigations were based upon a network of oceanographic stations at 20-mile intervals that extended from the headwaters of the Bay out over the continental shelf. Stations were repeated during the same and subsequent years.

During 1938, stations were occupied during August and September. The vertical distributions of salinity and density (sigma-t) presented by Favorite and Pedersen (1959 a) show two of the most characteristic features of the Bay—the counterclockwise flow as shown by the density profile between Cape Seniavin and Cape Newenham (App. I Fig. 6); and the vertical homogeneity of the water column at the head of the Bay as shown by the salinity profile seaward of Cape Chichagof (App. I Fig. 7).

Another interesting feature revealed by the 1938 data was the thermal stratification of the water column. Values of temperature, salinity and current speed at station 30–6 are shown in Appendix I Table 1. Between 15 and 16 metres depth the temperature decreased 4.76°C. In this particular case, the water column was essentially isohaline. Current speeds show no appreciable change in the area of the temperature discontinuity indicating that solar heating is the dominant cause of the temperature structure.

Appendix I Table 1.

Station 30–6 Z	57°00′N.; 160°37′W. Temperature	August 15, 1938 Salinity	Speed
0	(10.76)	(31.85)	*
5	(10.66)	(31.85)	*
10	(10.44)	(31.85)	*
12	*	*	.59
15	10.39	31.85	.49
16	5.63	31.85	.40
17	5.13	31.87	.48
18	4.97	31.85	.44
19	5.00	31.87	.42
20	4.97	31.87	.47

( ) Observation recorded two hours earlier—vessel anchored.
* No observation made.

Extensive hydrographic and current data were collected during May to August, 1939 (Favorite *et al.*, 1961). Surface current measurements, obtained by observing the set and drift of a drift-stick released from the anchored vessel at various locations provided a fairly comprehensive picture of tidal currents (App. I Fig. 8). The water in the Bay oscillated in a northeast-southwest direction. Velocities in excess of two knots occurred along the shore and considerably reduced velocities were found in the central part of the entrance of the Bay. Thus, even though the survey was as synoptic as possible utilizing one ves (approximately 2-hour time interval between station the structure probably varied rapidly and considerabl Nevertheless, stations occupied as many as three tim during the period May to August permit a gross pi ture of conditions in the Bay during the spring a summer.

Temperature Distribution, 1939

Three locations that exhibit representative temper ture structures have been selected from the 1939 da (App. I Fig. 9). The observations were obtained June, July, and August.

At the entrance to the Bay (Station A) the Ju temperature structure was isothermal at approximate 1°C. We can assume from Appendix I Figure 3 th during winter the temperature was about −1.5° Thus, by June, heat from solar incident radiation h been distributed uniformly throughout the wat column and increased the temperature of the wat column by about 2.5°C. We can also assume th some of the radiation had been utilized to melt t supposed ice cover. During June and July, most the heat gain was confined to the upper 10 metr resulting in a sharp 6°C. thermocline. As implied Appendix I Figure 4, and as will be shown in the ne section, the water column was essentially isohalin thus, the water column may be considered therma stratified and the 1.5°C. temperature increase in t lower layer was the result of diffusion, and advectic By August, surface cooling and mixing had alrea begun as evidenced by the deepening of the therm cline. However, as shown subsequently in the d cussion of surface temperatures, another process w involved in cooling the surface waters in the centr part of the Bay, and maximum surface temperatu of about 10°C. can be expected in late summer.

At Station B in June the waters near the surface we warmer than at A and were in the 5°C. range. T increase in heat content is believed to be due to t shallow depth, which presented a smaller water colur to be heated, as well as the fact that part of this wa column was fed by the river runoff which gain additional heat while passing over the warm and ve shallow flats at the head of the Bay. During July a August there was a progressive increase in the wa temperatures to 10°C., and tidal and wind mixi usually resulted in isothermal conditions.

Conditions at Station C were similar to those Station B; but, because the depths were considera shallower, the waters were correspondingly warm By August, temperatures in the 12°C. range w evident. Thus, in winter, the offshore conditions

ermal at about −1.5°C. and during spring and mer a pronounced shallow thermocline develops. egins to decay in late summer or early autumn. reas inshore, where similar winter conditions can ssumed to prevail, a minor thermocline develops pring, but quickly disappears in summer.

orizontal temperature distribution indicates that e was a sharp separation between the inshore and hore areas. Surface temperatures during May June (App. I Fig. 10) showed a marked tem- ature front lying along a line from Port Heiden to e Peirce; seaward of the front, temperatures in 1°C. and 2°C. range were found, and a counter- kwise flow was indicated. However, shoreward ne front the isotherms showed the presence of an- r more pronounced counterclockwise eddy or . It appears that the warm dilute runoff has n contained eastward of the Cape and been forced ecirculate shoreward of the front. The absence of ndication of this inshore gyre in the bottom tem- ature distribution (App. I Fig. 11) implies that feature is confined to the surface. The time in- al and area involved indicate that this is not a tidal nomenon.

y August, the generally accepted peripheral nterclockwise flow in the Bay is evident from the face isotherms (App. I Fig. 12). However, just ore of the temperature front which extended across Bay in spring, an anomalous region of cold tem- atures occurred which is interpreted as an area of velling. Again, as in spring, the bottom tempera- e distribution (App. I Fig. 13) shows an almost form gradient of temperatures from the head of Bay seaward. The area of cold temperatures at surface, indicative of upwelling, and a similar dient of bottom temperatures were also present in gust 1938.

Appendix I Figure 14 which shows the difference ween surface and bottom temperatures during gust 1939 clearly indicates the absence of any rmocline in the water column inshore of a line be- en Port Heiden and Cape Peirce. One would also ect to see a considerable difference in the turbidity l water colour on either side of this boundary, but data are available.

Salinity Distribution, 1939

The salinity distribution in the Bay corresponded the temperature distribution. As shown in Ap- ndix I Figure 4, the 1955 winter conditions show water structure to be isohaline with the central lf area having a salinity of about 31.8‰. Appendix Figure 15 shows the vertical distribution of salinity during June, July, and August 1939 at the same stations (A, B, and C) discussed in the temperature section.

At location A the water column was isohaline at about 31.8‰ during all three months. At B, which was further inshore, isohaline conditions also prevailed. Dilution occurred in July, but in August more saline conditions were encountered. This is due to an intrusion from the southwest which is evident in the horizontal distributions that follow. An adjacent station reflected the progressive dilution characteristic of the inshore area, which was clearly reflected in the values at C during August. By late August, the temperatures reached a maximum and began to decrease, however, there is evidence that further dilution occurred after this period. The absence of an appreciable halocline offshore at Position A implies that the river runoff moved counterclockwise along the coastline and did not extend to the central part of the Bay.

Surface salinities during May–June, 1939 (App. I Fig. 16) also indicate an inshore counterclockwise gyre which moved coastal dilution southward, inshore of the temperature front previously discussed. The differences in salinity values between the surface and bottom (App. I Fig. 17) show the feature to be confined to the surface waters at the head of the Bay. By August (App. I Fig. 18) the tongue of dilute water had been transported northwestward out of the Bay. The low salinity values at the head of the Bay indicate that there still was an extensive extrusion of runoff into the Bay in late summer. Salinity distribution at the bottom is shown in Appendix I Figure 19.

Approaches to Bristol Bay

In 1940 part of the emphasis of the *Redwing* investigations was shifted seaward of the Bay and this permits showing a possible source of the upwelled water.

The surface temperatures in August (App. I Fig. 20) varied from 5°C. to 11°C. The low temperatures which are shown near the Pribilof Islands are attributed to turbulence and a downward transfer of heat rather than any unusual source of cold water from the oceanic areas. The warmest water is found, as would be anticipated, along the shores of Bristol Bay. The cold area in the central part of the mouth of the Bay between Port Heiden and Cape Peirce is also evident.

Bottom temperature contours (App. I Fig. 21) coincide with the bottom topography. The cold area eastward of the Pribilof Islands is believed to reflect the delay in melting of offshore ice, and thus a delay of seasonal warming of the water column.

The bottom salinities (App. I Fig. 22) show a shoreward intrusion of oceanic water, between the Pribilof Islands and Unimak Island, which was confined seaward of a line between Port Heiden and Cape Peirce. The salinity distribution dominates the distribution of density as shown by the contours of sigma-t (App. I Fig. 23). However, it is impossible to ascertain from the data if the movement of water at these depths is along the isolines. If so, the oceanic water moves counterclockwise around the Bay. If it flows across the isolines the water intrudes into the Bay as a tongue or wedge resulting in an upward movement or upwelling.

Edge of Continental Shelf

A discussion of Bristol Bay would not be complete without showing the distribution of properties in the zone between the continental shelf and the oceanic area seaward of the shelf. In this case, the most complete data are from the cruise of the M/V *Attu* (Favorite and Pedersen, 1959 b).

Vertical profiles of temperature, salinity, dissolved oxygen and density are shown in Appendix I Figure 24.

The line of stations did not extend far enough onto the shelf to show the cold temperatures, characteristic of this area, as shown in Appendix I Figure 21. Surface warming had already begun; hence, there was very little indication of the changes in temperature conditions as one approaches the shelf from seaward that are evident in the salinity profile structure. Values of dissolved oxygen greater than 0.7 mg. at./l. near, and over the shelf, indicate high phytoplankton population.

Although solar heating in spring and summer tends to make the surface temperatures relatively uniform over and seaward of the shelf, the presence of ice, or the temperatures that exist immediately after the ice has melted, reveal a marked change in environment at the edge of the continental shelf. Data collected aboard the M/V *Tordenskjold* (Love, 1959) during 1956 illustrated this condition (App. I Fig. 25).

Summary

Bristol Bay is characterized by an extensive shallow continental shelf which isolates the Bay from the oceanic circulation systems, and by an extensive watershed surrounding the Bay which releases large amounts of snowmelt and fresh-water runoff into the Bay from early spring to late autumn. The combination of these features and the wind and tidal systems result in a relatively constant annual cycle of environmental conditions, which are in sharp co trast to those of the adjacent Bering Sea. The boun ary between the shelf area and the deep Bering S basin, delineated by the sharp continental slope, also evidenced by changes in physical and chemic properties of the water column.

In early autumn, the heat content of the shallow B is quickly dissipated. Cold air temperatures ar dilute surface water permit the early formation of i along the shores, and by winter, ice is present over large part if not all of the Bay. During winter, ter peratures and salinities of approximately −1°C. ar 31.6‰ occur in the ice fields; whereas, in contrast, t central Bering Sea is usually void of ice and temper tures from 2°C. to 3°C. and salinities of 33.0‰ 33.4‰ occur at the surface.

The ice cover in the Bay retards the spring warmi of the surface layer, but melting of the ice dilutes t surface layer causing sufficient vertical stratificati to confine the rapidly increasing net heat gain to t upper 10 to 20 metres of the water column. In t inshore area the temperatures reach 12°C. to 13° and the water column is isothermal. In the offsho area, summer heating results in the formation of shallow, sharp thermocline with a magnitude of 5° to 8°C. in mid-summer. Surface temperatures rea 10°C. to 11°C. In late summer, wind mixing, adve tion and vertical diffusion can raise the bottom te peratures in the offshore waters to temperatures 3°C. to 4°C. or higher.

The movement of water in the Bay, as implied the distribution of properties, is counterclockwi Drift stick and direct current measurements indica the water in the Bay oscillates with a tidal period fro the surface to the bottom in a northeast-southw movement; however, slope currents induced by t wind, and pressure distributions in the Bering S must also produce short and long term effects on t general flow which were not obvious in these curre measurements.

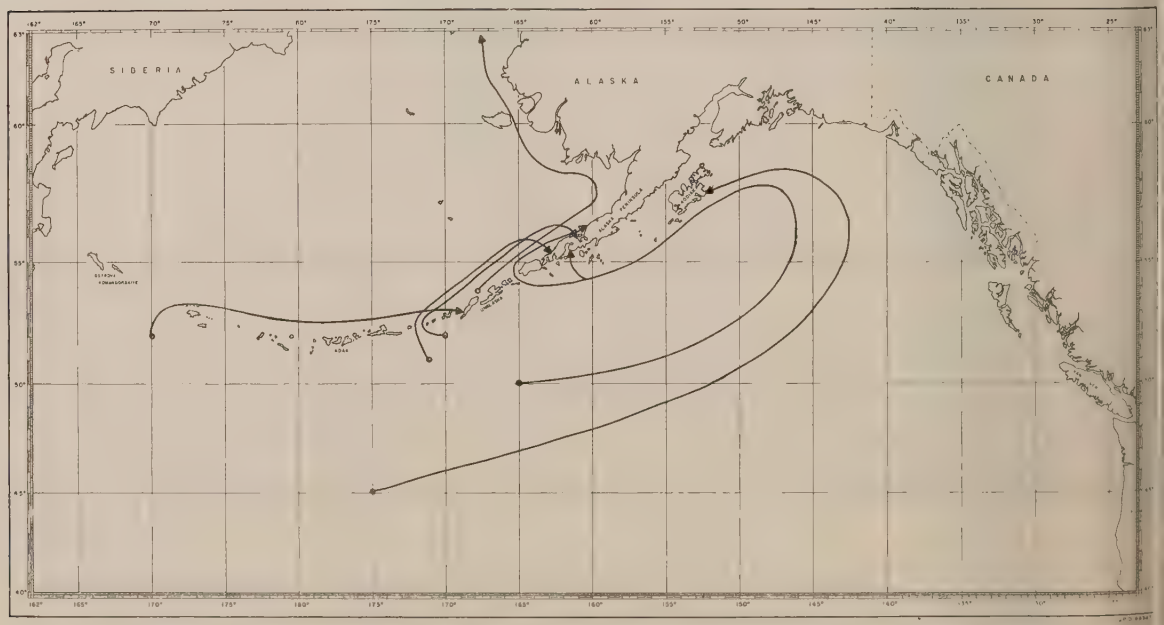
One of the striking oceanographic features of the B is the evidence of a sharp boundary between the hea waters and the offshore waters. This occurs in t central part of the Bay along a line between Ca Peirce and Port Heiden and appears to be associat with a vertical movement of water intruding over t continental shelf between the Pribilof Islands a Unimak Island.

References

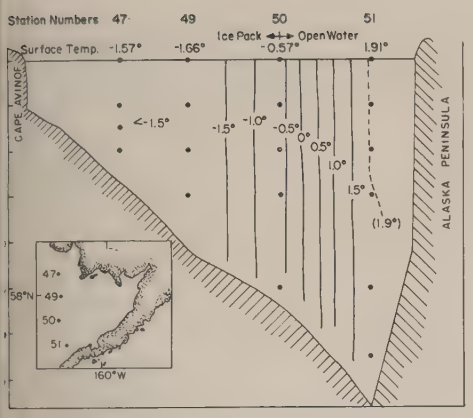
Favorite, Felix, and Glenn Pedersen. 1959a. Bristol I oceanography, August—September 1938. *U.S. Fish*

Wildlife Service, Special Scientific Report-Fisheries, No. 311, 31 pp.
ORITE, FELIX, and GLENN PEDERSEN. 1959b. North Pacific and Bering Sea oceanography, 1958. *U.S. Fish and Wildlife Service, Special Scientific Report-Fisheries*, No. 312, 230 pp.
ORITE, FELIX, JOHN W. SCHANTZ and CHARLES R. HEBARD. 961. Oceanographic observations in Bristol Bay and the Bering Sea 1939–41 (USCGT *Redwing*). *U.S. Fish and Wildife Service, Special Scientific Report-Fisheries*, No. 381, 323 pp.
BARD, J. F. 1959. Currents in southeastern Bering Sea and possible effects upon king crab larvae. *U.S. Fish and Wildlife Service, Special Scientific Report-Fisheries*, No. 293, 11 pp.
VE, C. M. 1959. Physical and Chemical Data, North Pacific Ocean, Gulf of Alaska and Bering Sea, Summer of 1956. *University of Washington, Department of Oceanography, Special Report*, No. 31, 231 pp.
SAUR, J. F. T., R. M. LESSER, A. J. CARSOLA and W. M. CAMERON. 1952. Oceanographic cruise to the Bering and Chukchi Seas, summer 1949. Part III: Physical observations and sound velocity in the deep Bering Sea. Report 29B. U.S. Navy Electronics Laboratory, San Diego, California. 38 pp.
U.S. COAST PILOT 9. 1954. Alaska. Cape Spencer to Arctic Ocean. Department of Commerce, United States of America, 673 pp.
U.S. NAVY HYDROGRAPHIC OFFICE. 1958. Oceanographic survey results, Bering Sea area, winter and spring 1955. *U.S. Navy Hydrographic Office, Technical Report* 46, 95 pp.

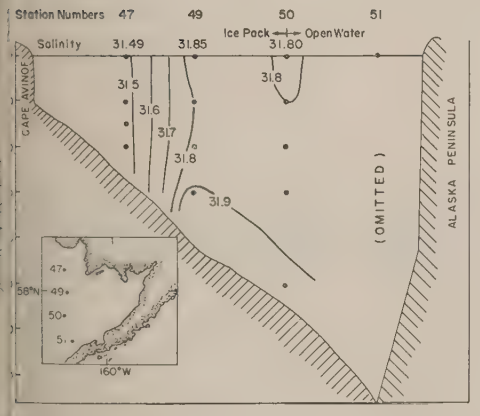
Appendix I Figure 1. General area chart showing selected contours of bottom topography in metres. (25, 50, and 75 metre contours not shown southward of Alaska Peninsula.)



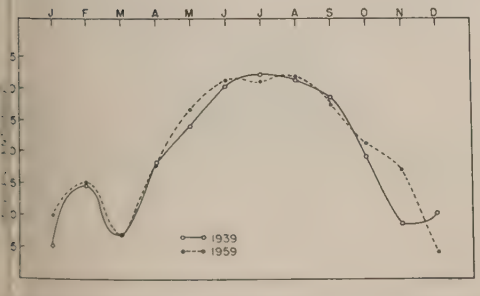
Appendix I Figure 2. Release and recovery points of selected drift bottles (B.C.F., Seattle, Wash.).



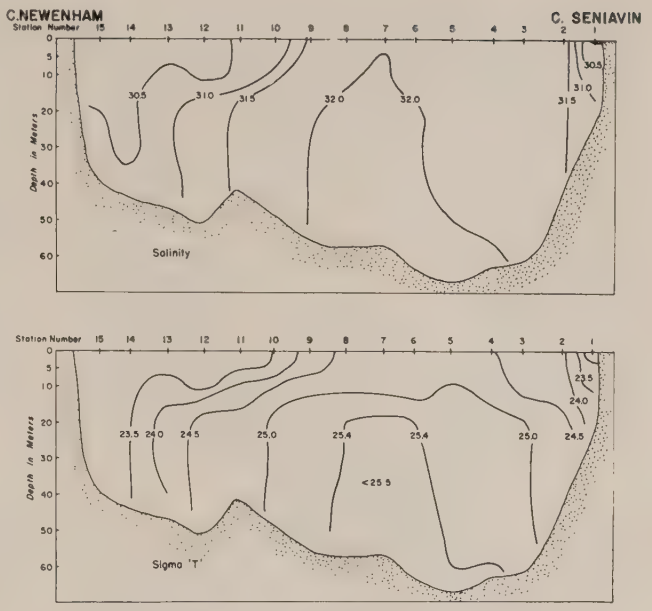
APPENDIX I FIGURE 3. Vertical profile of temperature (°C.) at entrance to Bristol Bay, winter 1955.



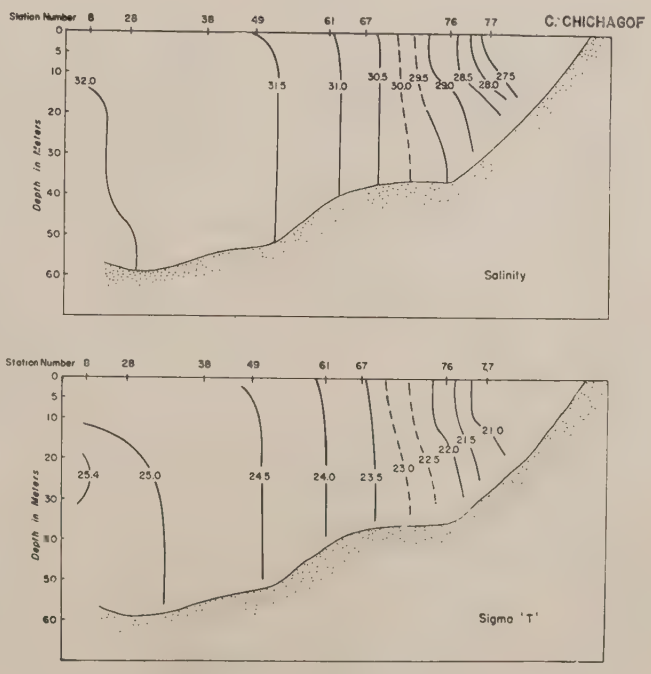
APPENDIX I FIGURE 4. Vertical profile of salinity (‰) at entrance to Bristol Bay, winter 1955.



APPENDIX I FIGURE 5. Comparison of average monthly air temperatures during 1939 and 1959 at Dillingham, Alaska.



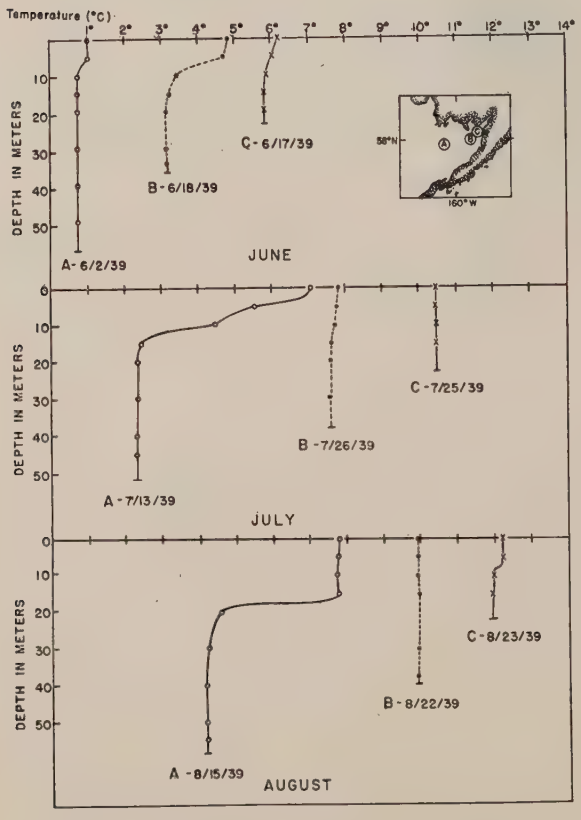
APPENDIX I FIGURE 6. Vertical profiles of salinity and sigma-t between Cape Seniavin and Cape Newenham, August 1938.



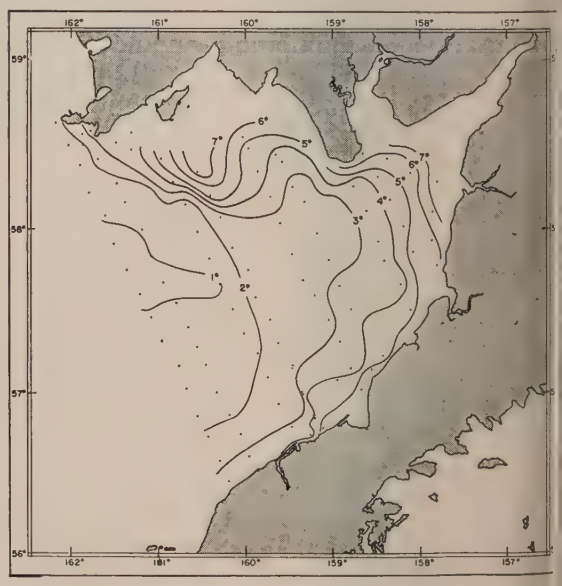
APPENDIX I FIGURE 7. Vertical profile of salinity and sigma-t seaward of Cape Chichagof.

APPENDIX I FIGURE 8. Surface drift-stick observations, 1939.

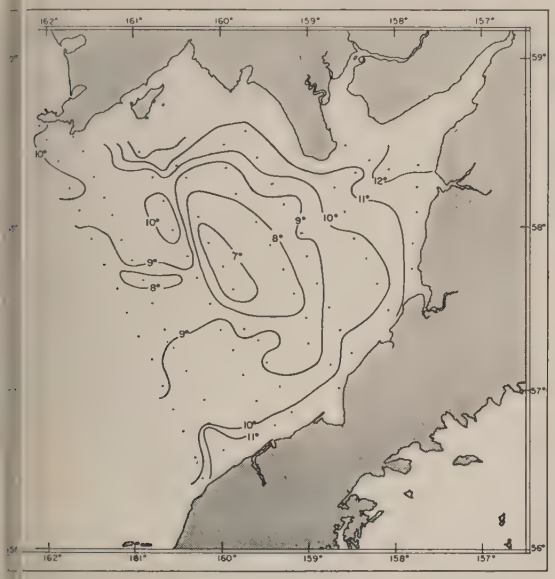
APPENDIX I FIGURE 10. Surface temperatures (°C.), May-June 1939.



APPENDIX I FIGURE 9. Vertical temperature structure at three selected stations, 1939.



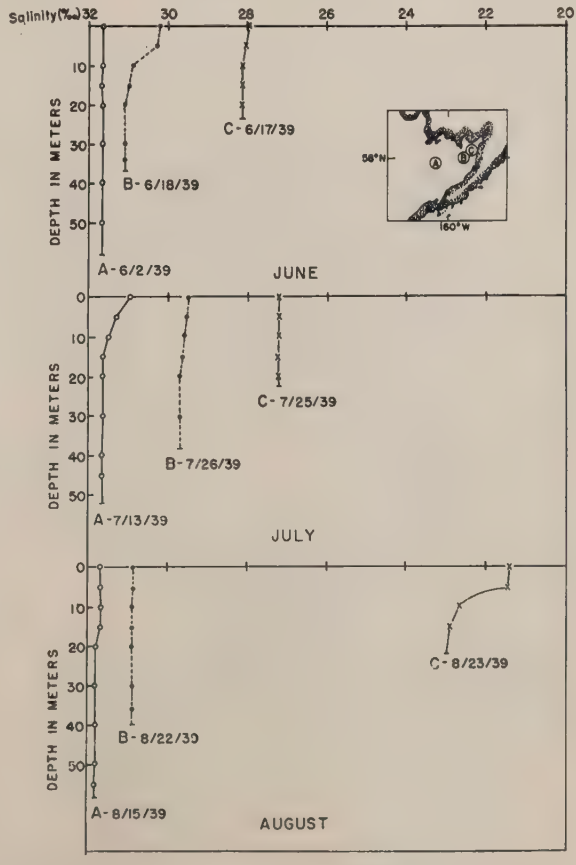
APPENDIX I FIGURE 11. Bottom temperatures (°C.), May-June 1939.



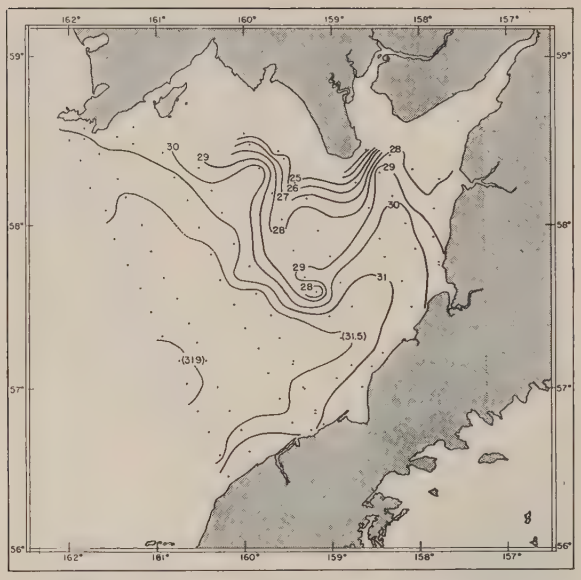
APPENDIX I FIGURE 12. Surface temperatures (°C.), August 1939.

APPENDIX I FIGURE 13. Bottom temperatures (°C.), August 1939.

APPENDIX I FIGURE 14. Difference in temperature (°C.) between surface and bottom, August 1939.

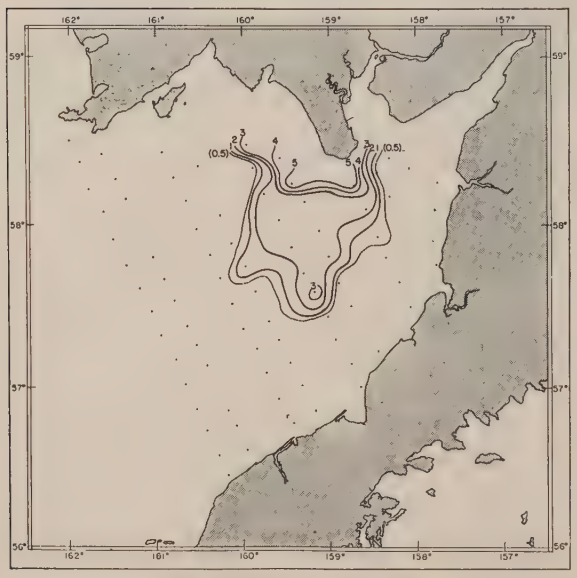


APPENDIX I FIGURE 15. Vertical salinity structure at three selected stations, 1939.



ANPPNEDIX I FIGURE 16. Surface salinity (‰), May–June 1939.

APPENDIX I FIGURE 18. Surface salinity (‰), August 1939.

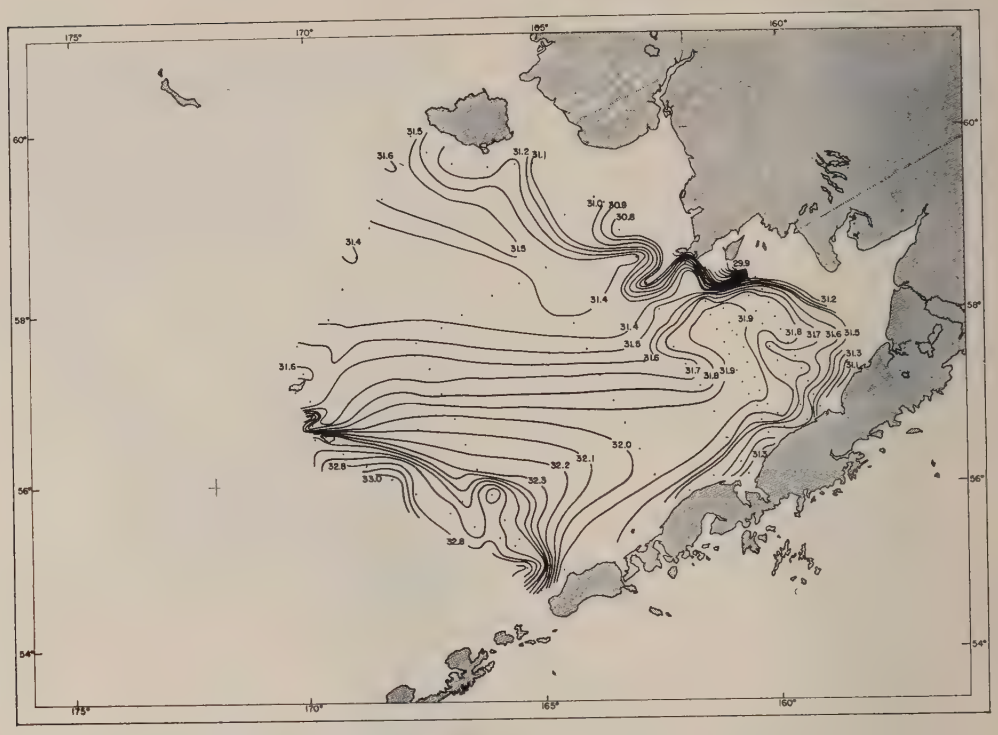


APPENDIX I FIGURE 17. Difference in salinity (‰) between surface and bottom, May–June 1939.

APPENDIX I FIGURE 19. Bottom salinity (‰), August 1939.

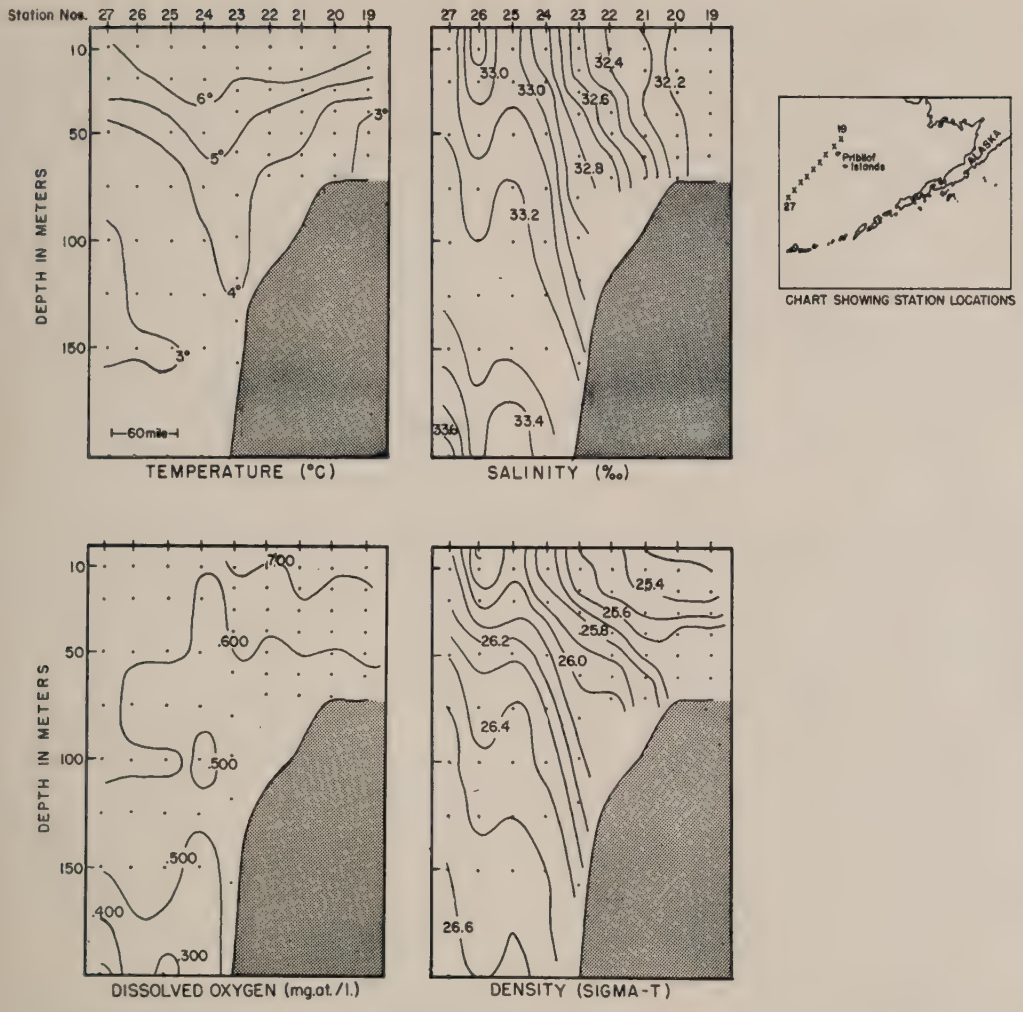
APPENDIX I FIGURE 20. Surface temperatures, July–August 1940.

APPENDIX I FIGURE 21. Bottom temperatures, July–August 1940.

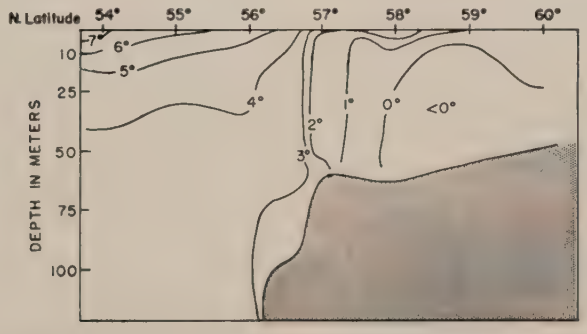


Appendix I Figure 22. Bottom salinity, July–August 1940.

Appendix I Figure 23. Bottom sigma-t, July–August 1940.



Appendix I Figure 24. Vertical profiles of properties near the edge of the continental shelf, June 1958. (Shelf indicated by stippling.)



Appendix I Figure 25. Vertical profile of temperature near the edge of the continental shelf at 170°W., June 1956. (Shelf indicated by stippling.)

APPENDIX II: REVIEW OF OCEANOGRAPHY OF THE WATERS NEAR THE WEST COAST OF VANCOUVER ISLAND, BRITISH COLUMBIA

Lane (1962a, b) has recently reported on the oceanography of the waters off the west coast of British Columbia. The following is a brief review of these studies.

Beginning with a study of Nootka Sound in 1933 (Tully, 1937) Canadian oceanographers have carried out investigations in the coastal areas. Many of these were localized studies, while others attempted to define and describe the more general distributions in the coastal waters.

The local studies include those in Nootka Sound (1933); Barkley Sound (1937, 1950, 1953); the approaches to Juan de Fuca Strait (1937, 1938); Dixon Entrance (1938); the Swiftsure area (1938); and in the area about La Perouse Bank (1960). These areas are identified in Appendix II Figure 1.

Those cruises operating in a more extensive area were the coastal surveys, which covered the shelf area off Vancouver Island (1935, 1936); and off the Queen Charlotte Islands (1935); the offshore survey (1936), which operated seaward from the north, central and southern portions of Vancouver Island; Project Offshore (1950–52), reported by Doe (1955). The more recent cruises are the coastal surveys (1957) which included the area from 46°N. to 56°N. to about 200 miles offshore; the Coastal Seaway cruises (1958, 1959), which monitored several lines of stations seaward of both Vancouver Island and the Queen Charlotte Islands; and the Seaways Program (1960–61) which was a modification of the latter.

The data from all these expeditions have been processed and most of them have been reported (Pacific Oceanographic Group, MS, 1957–60). These reports also include daily seawater observations of temperature and salinity from 21 locations along the British Columbia coast, for varying periods; some since 1933. Recently Tabata (1959) and Hollister (1960) have presented a system of classifying the monthly means of these observations. This classification was undertaken to assist in the work of establishing correlations between fisheries statistics and coastal oceanographic conditions.

Meteorological data are available in the records and publications of the Meteorological Division, Department of Transport. River discharge data are available from records and publications of the Water Resources Division, Department of Northern Affairs and National Resources, Canada, and Water Resources Division, United States Department of the Interior.

Studies of these data have shown that the coastal area is not wholly dominated by oceanic influences as are most coastal areas in other parts of the world. Instead, the oceanography of the Canadian coastal area is determined by the relative influence of the considerable estuarine discharge and the character of the oceanic waters. A study of the oceanic circulation has shown that off the North American coast the ocean waters separate to form the California Current and the Alaskan Gyre. The area of separation is continually shifting, hence the character of the oceanic water adjacent to the coast varies considerably. The estuarine discharge from the many inlets varies with precipitation and snow storage. In addition, the area is subject to variable winds and strong tides. However, none of these studies were adequate to observe the seasonal sequence of events and to define the mechanisms.

An examination of these data by Lane (1962) showed that although such features as seaward and vertical gradients, and the coastwise continuity are real there were considerable variations in short distance and short times which complicate and frequently negate the basic trend. Thus, it was not possible to assume simple continuity between widespread lines of observations, such as seaward from the southern, central and northern ends of Vancouver Island, nor was it reasonable to assume more than a first order consistency of structure. In addition, short term variations were as great or greater than the seasonal or yearly variations.

In a second paper Lane (1962 b) concentrated attention on the considerable data from a local area and assessed the variability and its relation to causative factors (insolation, wind, precipitation, and tide). The area in which sufficient data were available was that seaward of Amphitrite Point (App. II Fig. 3). It is also the widest expanse of the coastal area. He subdivided this area into three belts—each belt having some distinct oceanographic features of structure. The positions of these belts (Inshore, Shelf and Slope) are shown in Appendix II Figure 2. In these belts he was able to deduce a model of temperature and salinity structure and related the major oceanographic features of the model to tides and meteorological elements. It is considered that these ideas, when amplified and extended will lead to a reasonable understanding of the coastal phenomena. At the mom

description entails much simplification. It is ly discussed.

he model defines the annual sequence of tempera- and salinity structure in five seasonal stages . II Fig. 3 to 7) where the letters define the r masses:

	Oceanic	Coastal
Upper Zone	OU	CU
Halocline	OH	CH
Lower Zone	OL	CL

age 1 (App. II Fig. 3), from December through ch, is in general a period of strong southeast winds, mum insolation, maximum cooling and runoff. latter, in this case, is a result of local precipitation istinct from that in the spring which is associated mainland rivers and the spring thaw of high ons of ice and snow. The strong southeast winds to a condition of convergence and vertical mixing. se associated with cooling lead to a relatively nar- northward flow of cool, well-mixed and brackish er along the coast.

age 2 (App. II Fig. 4), through March and April, rgely a period of variable winds, increasing insola- and decreasing runoff. The convergence mech- m relaxes and the brackish water tends to spread ard. This condition attains fulfillment in Stage 3 p. II Fig. 5), the period May through July. Also is time, the mainland rivers are in freshet and tidal on conduces to the formation of large pools of kish water. Because of these pools, there are ked short term variations in the near-surface ers.

tage 4 (App. II Fig. 6), from July through October, urs during the prevalence of weak northwest winds minimal fresh-water discharge from the land. A k divergence condition may enhance the spread of brackish water seaward. On the other hand, persistent northwest winds will produce a strong divergence condition, in which case there is not only a spread of brackish water seaward but also a replenishment of these waters from depth, resulting in a breakdown of the new coastal structure and the appearance of relatively cold saline waters. Such conditions have been observed but are not necessarily the persistent characteristics of the area.

Stage 5 (App. II Fig. 7), from October through December, is a time of increasing southeast winds and precipitation. During this stage the oceanic upper zone (OU) deepens. This results in an intensification of the top of the oceanic halocline (OH). Its base descends due to the advent of convergence.

References

Doe, L. A. E. 1955. Offshore waters of the Canadian Pacific Coast. *J. Fish. Res. Bd. Canada*, 12(1): 1–34.

Hollister, H. J. MS, 1960. Classifications of seawater temperature and salinity on the Pacific Coast of Canada. 1915–1959. Fish. Res. Bd. Canada, MS Rept. Series, Oceanogr. and Limnol., No. 68, 139 pp.

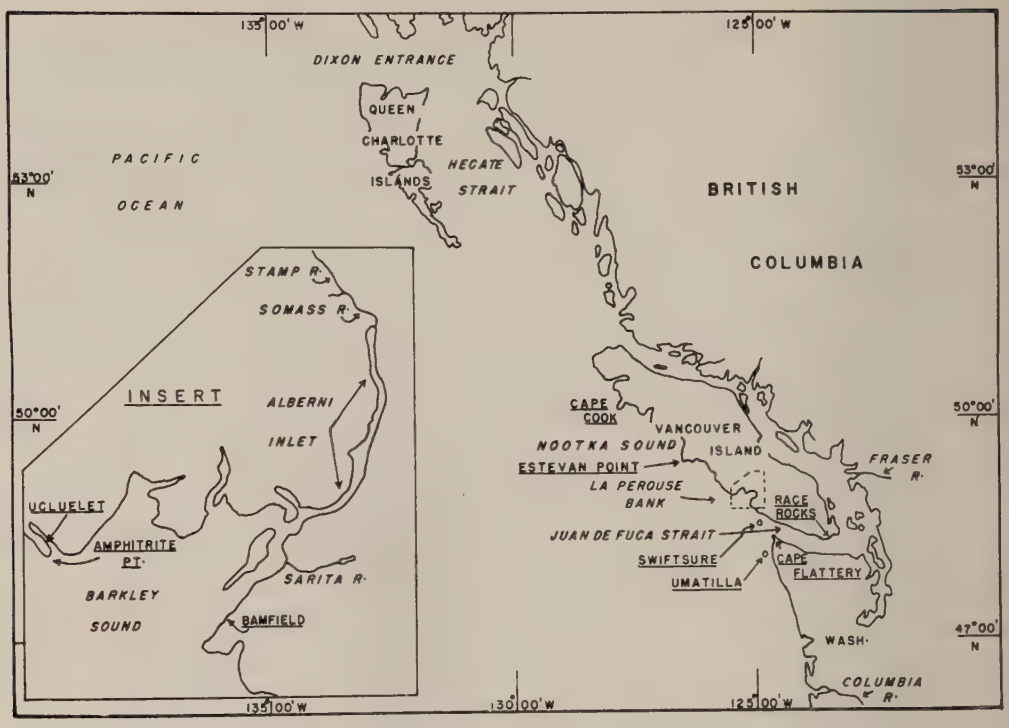
Lane, R. K. 1962a. Oceanographic features in approaches to Vancouver Island, B. C. *J. Fish. Res. Bd. Canada*, 19(1): 45–91.

Lane, R. K. 1962b. A model of seawater structure near the West Coast of Vancouver Island, British Columbia. A thesis submitted to Oregon State University in partial fulfillment of requirements for the degree of Master of Science, July 1962.

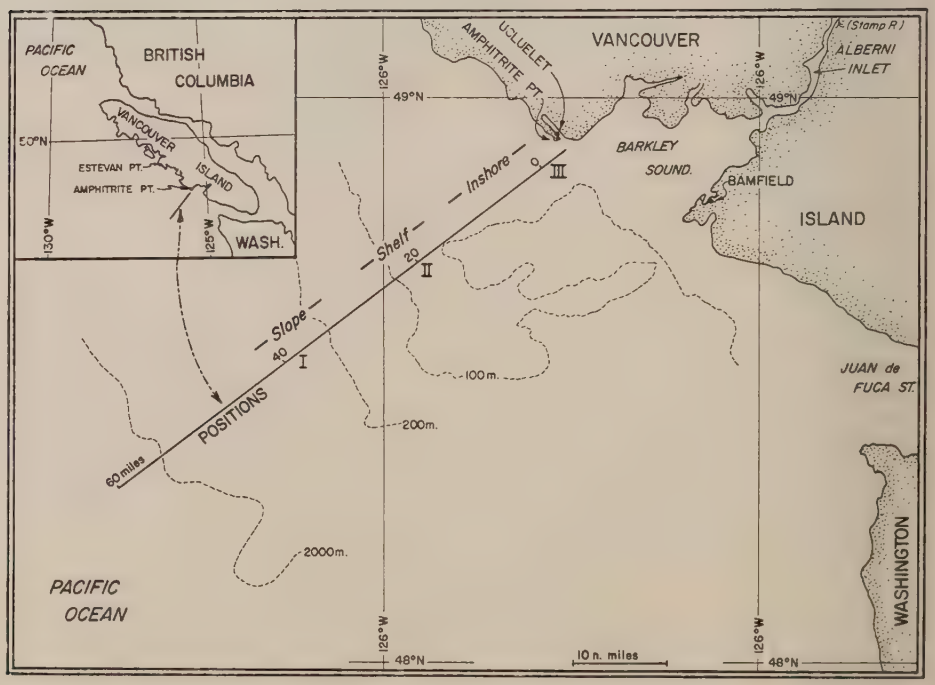
Pacific Oceanographic Group. MS, 1957–60. Data records. Fish. Res. Bd. Canada, MS Rept. Series, Oceanogr. and Limnol., No. 16, 17, 23, 29, 36, 43, 47, 48, 52, 54, 58, 63, 67, 70, 76, 82, 83, 84.

Tabata, Susumu. 1957. Classification of daily seawater data. *Trans. Amer. Geophys. Union*, 38(1): 191–197.

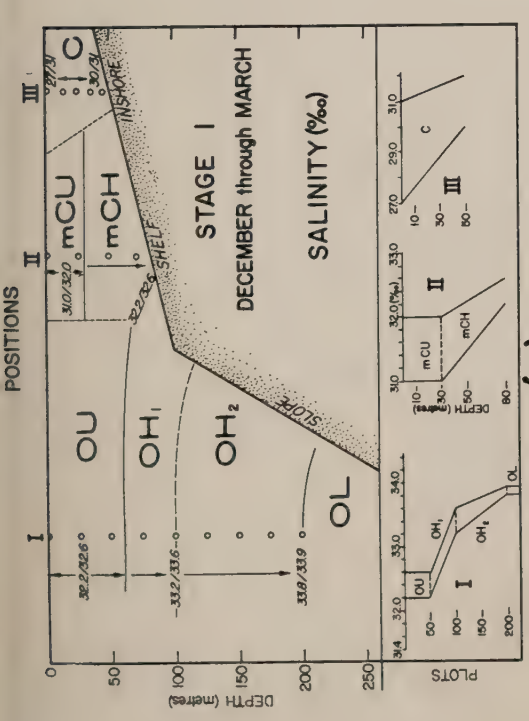
Tully, J. P. 1937. Oceanography of Nootka Sound. *J. Biol. Bd. Canada*, 3(1): 43–69.



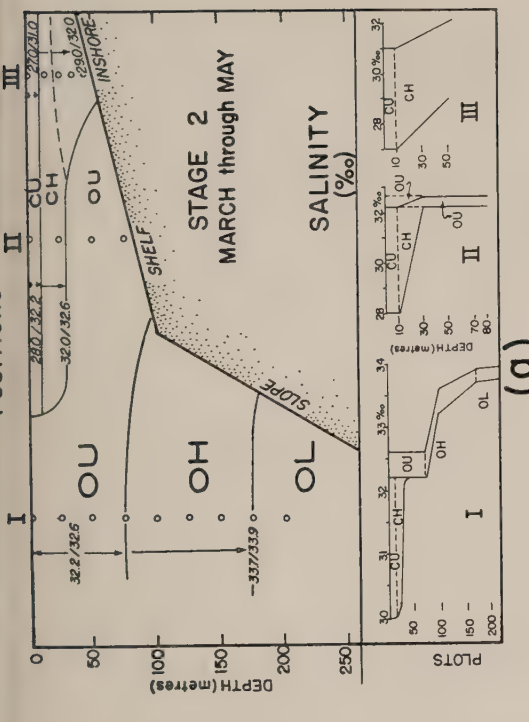
Appendix II Figure 1.



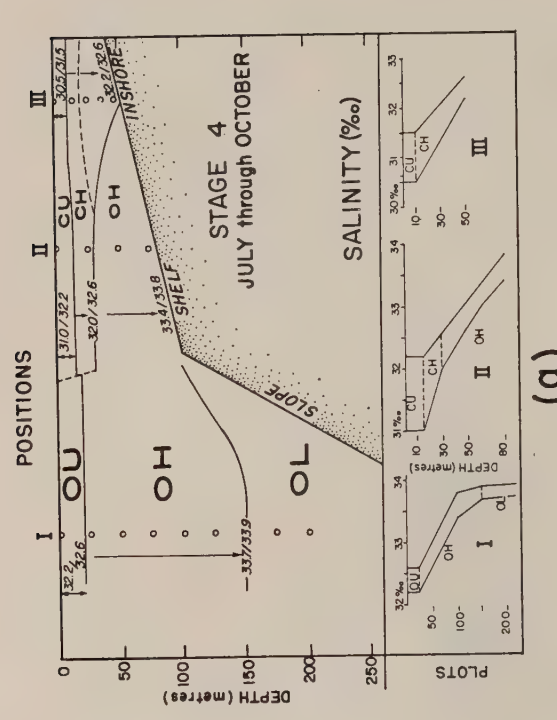
Appendix II Figure 2.

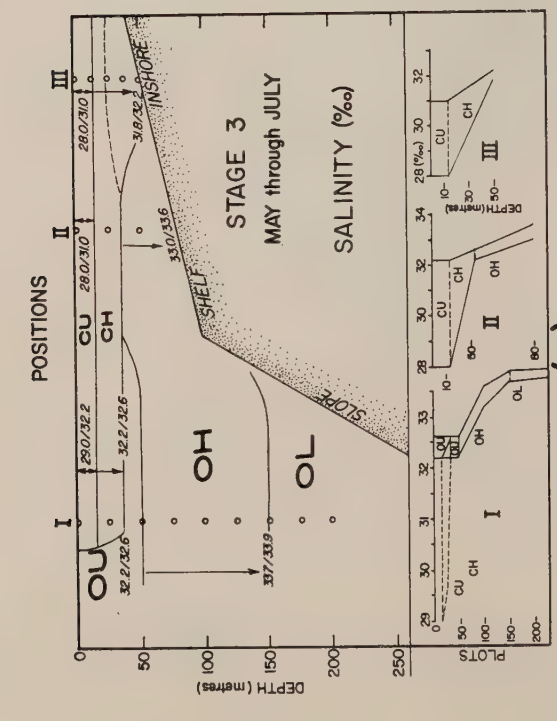


Appendix II Figure 3.

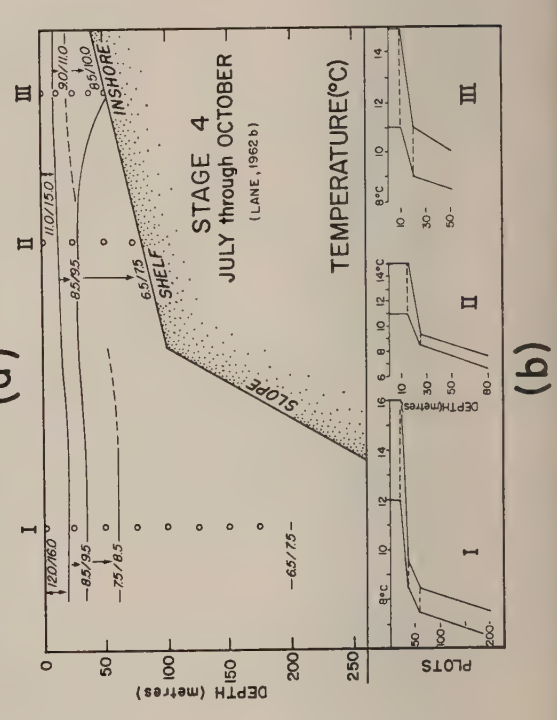


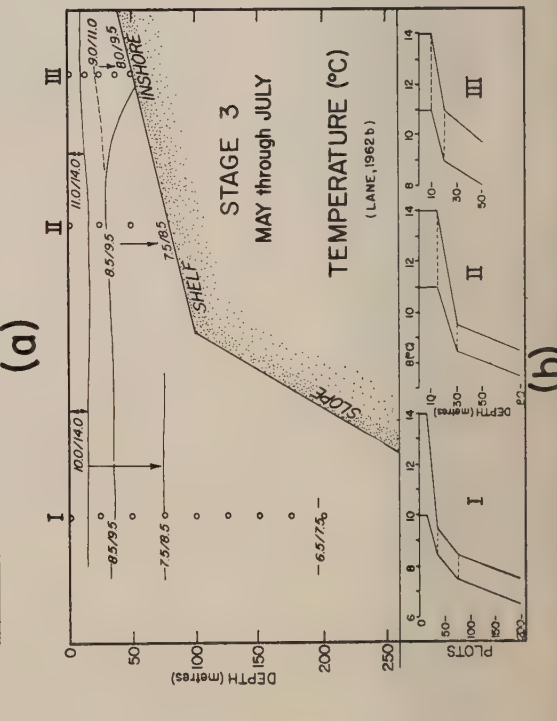
Appendix II Figure 4.



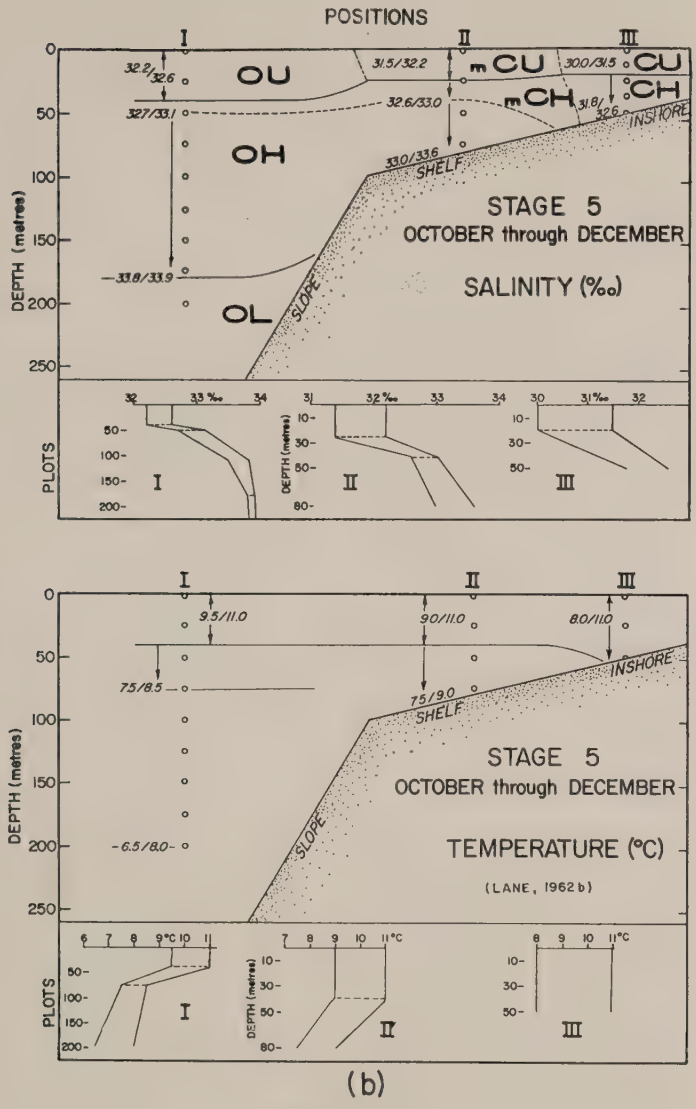


Appendix II Figure 6.





Appendix II Figure 5.



(b)

Appendix II Figure 7.

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Alexander Dragovich

In characterizing a marine environment ecologically, studies of aquatic conditions (Harvey, 1957; Rochford, 1951) and plankton as indicator organisms (Cleve, 1900; Russell, 1939) are extremely important.

The object of this work was to make concurrent studies of plankton occurrence and hydrology as well as to determine the influence of precipitation on them. Occurrence of the red-tide organism, *Gymnodinium breve* Davis (1948), was of particular interest in this study, since the Florida red tide is a natural fish-killing phenomenon in the coastal waters of southwest Florida. Monthly variations in temperature, salinity, total phosphate phosphorus, inorganic phosphate phosphorus, nitrate-nitrite nitrogen, substances which react to tests for arabinose and tyrosine, and characteristic plankton forms were investigated. A second objective was to observe the influence of precipitation upon the hydrology and plankton.

In recent years, the chemical and biological properties of Gulf waters of the west coast of Florida have been studied by various authors (Gunter *et al.*, 1948; Lasker and Smith, 1954; Ketchum and Keen, 1948; King, 1950; Graham *et al.*, 1954; Graham, 1954; Collier, 1958a; Curl, 1959a, 1959b; Finucane and Dragovich, 1959; Pomeroy, 1960; Dragovich *et al.*, 1961), but very little simultaneous hydrological and planktonic information is available for southwestern Florida waters.

The data on which this study is based have been published elsewhere (Dragovich, 1961).

Materials and Methods

All water samples were collected from the surface at Naples Pier, Naples, Florida, latitude 26° 07.9′, longitude 81° 48.5′. Sample collection procedure, plankton counting technique, and chemical methods of analysis were those described by Dragovich (1961). Organisms were enumerated in the living state. All Florida identifications and distributions not otherwise ascribed are by the au-

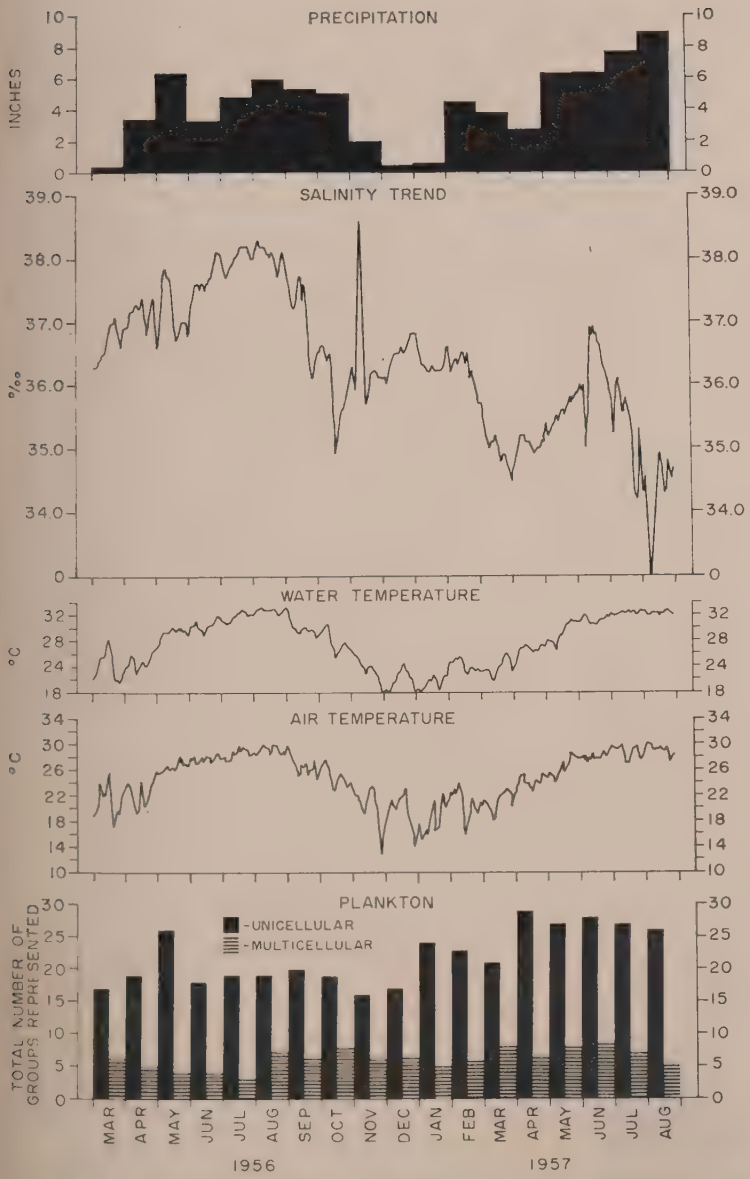

Fig. 1. Precipitation, salinity, water temperature, air temperature, and plankton for the surface water at Naples, Florida, March 1956-August 1957.

thor. Notes on species and distributions in other Gulf of Mexico waters not otherwise ascribed are from unpublished records of the Biological Laboratory of the Bureau of Commercial Fisheries at Galveston, Texas. When another source is also cited, these unpublished data will be indicated by (BCF).

Hydrological Observations

The maximum (31.9° C.) water temperature was recorded in August 1956 and the minimum (17.0° C.) in November 1956 and January 1957. The monthly mean temperatures varied from 19.5° C. in January 1956 to 30.8° C. in August 1956. A relatively sharp rise occurred from April to May 1956 and a sharp decline from October to November 1956 (figure 1). Unusual spells of warm weather were recorded during March-April 1956 and from December 1956 through February 1957. During the remaining portion of this investigation, the seasonal temperature changes were gradual. The air temperature varied from 7.5° C., in January 1957, to 30.8° C., in July 1956. The monthly distribution of water temperature was essentially that of the air temperature (figure 1).

The monthly salinity means varied from 34.4 o/oo in August 1957 to 38.0 o/oo in August 1956. From March 1956 to August 1956 a gradual increase in salinity was noted. From August 1956 to August 1957 there was a generally declining trend.

The year 1956 was characterized by relatively little precipitation (38.1 inches), whereas the year 1957 had heavy rainfalls (58.4 inches). The 20-year mean precipitation for the Naples area is 51.50 inches. Precipitation values in figure 2 are the means of monthly rainfall recorded at weather centers in Naples, Miles City Tower, Everglades, and Fort Myers. Fort Myers, Everglades, and Miles City Tower are located within a 38-mile radius to the north, south, and east of Naples, respectively. All four of these weather centers are within the drainage basin of Everglades swamps, which drain their waters into the Gulf of Mexico.

The concentrations of total phosphorus in 69 water samples collected over a period of 17 months varied from 0.2 to 17.4 microgram atoms per liter (μg.at./l) with a mean of 1.5 μg.at./l (Dragovich, 1961). The highest concentrations during 1956 were observed in March and April. From April 1956 to May 1957 the concentrations remained below 2.0 μg.at./l. Unusually high values

Fig. 2. Incidence of plankton at Naples, Florida, March 1956-August 1957.

(17.4 and 12.7 μg.at./l) were recorded in May and June 1957. During July, the concentrations remained below 2.0 μg.at./l.

The frequency distribution of total phosphate phosphorus concentrations shows that the majority of values (69.6 per cent) ranged from 0.2 to 1.0 μg.at./l. In 20.3 per cent of observations the values ranged from 1.1 to 2.0 μg.at./l, but the range 2.1 to 17.4 μg.at./l was recorded in only 10.1 per cent of the samples.

Concentrations of inorganic phosphate phosphorus in 73 samples varied from 0.0 to 3.2 μg.at./l with a mean of 0.6 μg.at./l. With the exception of May and June 1957, the monthly distribution pattern of inorganic phosphate phosphorus was similar to that of the total phosphate phosphorus. The frequency distribution of values showed a range of 0.1 to 0.6 μg.at./l in 68.5 per cent of the samples; 0.7 to 1.0 μg.at./l in 19.2 per cent; and 1.1 to 3.2 μg.at./l in 12.3 per cent.

Concentrations of nitrate-nitrite nitrogen in 66 water samples collected in a period from May 1956 to July 1957 ranged from 0.0 to 4.4 μg.at./l, with a mean of 0.7 μg.at./l. The monthly distribution of nitrate-nitrite nitrogen was very irregular. Highest concentrations were observed during November 1956 and March 1957. The distribution of nitrate-nitrite nitrogen values shows that the majority of concentrations (62.1 per cent) varied from 0.0 to 0.6 μg.at./l. A range of 0.7 to 2.0 μg.at./l was observed in 33.3 per cent of the samples. High values (2.1 to 4.4 μg.at./l) were recorded in only 4.5 per cent of the samples collected during November 1956 and March 1957. The minimal nitrate-nitrite nitrogen values of 0.0 μg.at./l were recorded in 6.1 per cent of samples and occurred during July, August, and October 1956.

Concentrations of carbohydrates producing a positive arabinose test in 73 samples varied from 0.0 to 4.1 milligrams per liter (mg/l) with a mean of 1.2 mg/l, and total tyrosine in 71 water samples varied from 0.0 to 10.5 mg/l, with a mean of 1.1 mg/l. These carbohydrate and protein substances will be referred to hereafter simply as carbohydrates and proteins.

The monthly mean values of carbohydrates and proteins were irregular. The concentrations of carbohydrates during 1956, with the exception of some values in March, April, and December, exceeded those of proteins. In 1957, extremely high concentrations of proteins were observed during February, March, and July, at which time proteins greatly exceeded carbohydrates. The con-

centrations of carbohydrates were generally lower during 1957 than during 1956. The frequency distribution of carbohydrates and proteins showed that the majority (66.2 per cent) of protein concentrations varied from 0.0 to 0.6 mg/l, and the majority (63.0 per cent) of carbohydrate concentrations ranged from 0.7 to 2.0 mg/l.

PLANKTON OBSERVATIONS

The study included 48 unicellular and 13 multicellular taxa of plankton (Dragovich, 1961). The unicellular taxa consisted of 10 genera of diatoms, 26 genera of dinoflagellates (11 of which were identified to species), a group of silicoflagellates, a group of unidentified phytoplankton (5-12 μ in size), 2 euglenoid genera, 6 ciliate genera, 1 ciliate family, and 1 unidentified group of ciliates.

Diatoms were represented by five centrate genera: *Chaetoceros* Ehrenberg, *Guinardia* Perag, *Melosira* Agardh, *Rhizosolenia* (Ehrenberg, Brightwell) Perag, and *Skeletonema* Greville; and five pennate genera: *Thalassiothrix* Cleve and Grunow, *Navicula* Bory, *Nitzschia* Hassal, *Pleurosigma* W. Smith, and *Grammatophora* Ehrenberg. All genera consisted of several species. No species identification was made.

Chaetoceros, Melosira, and *Nitzschia* were the principal diatom genera observed, occurring every month during this investigation.

Chaetoceros, the most frequently occurring group of diatoms, was present in 49 per cent of all observations (figure 2). Although *Chaetoceros* spp. appeared throughout the observation period, their

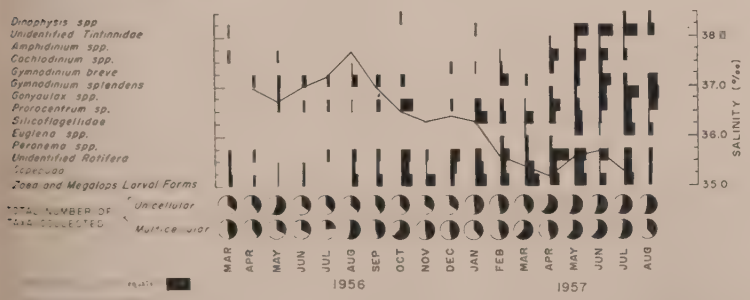

Fig. 3. Monthly incidence of selected planktonic groups, total number of taxa collected, and the salinity trend at Naples, Florida. Salinity trend represented by a three-item moving average of monthly salinity means.

presence in large numbers was noted only from May through September 1956.

Melosira and *Nitzschia,* the second and third most frequently observed groups of diatoms, showed similar monthly occurrence.

Rhizosolenia and *Guinardia* were present during most months, and blooms of these two groups were recorded during May 1956. A larger *Rhizosolenia,* resembling *R. styliformis* Brightwell, was on the whole, much scarcer than a smaller species.

Skeletonema and *Pleurosigma* had very limited occurrence. *Pleurosigma* occurred in small numbers. *Skeletonema* was predominant during April 1957.

Grammatophora appeared only during spring and summer months of 1957, occurring most frequently in April.

Navicula appeared during 9 months but never in high numbers.

Thalassiothrix was observed only in June and July of 1956 in small numbers.

The data indicate an influx of diatoms in May, June, August, and September of 1956. High concentrations of diatoms were observed in 1956, but 1957 was characterized more frequently by low concentrations.

Among dinoflagellates, the principal groups of organisms were *Gymnodinium* Stein, *Peridinium* Ehrenberg, and *Gyrodinium* Kofoid and Swezy (figure 2).

Gymnodinium spp. ranged from 5 to 40 μ. The smallest resembled *G. vitiligo* Ballantine and *G. veneficum* Ballantine; the largest resembled *G. heterostriatum* Kofoid and Swezy. *Gymnodinium* spp. occurred during every month; their abundance was consistently high from January through August 1957 at periods of reduced salinity and high precipitation.

The three gymnodinians identified to species are *G. splendens* Lebour, *G. simplex* Lohmann, and *G. breve* Davis.

G. splendens. Neritic and estuarine species. Common off west coast of Florida; off Galveston coast, Texas; and off Plymouth Sound, England (Lebour, 1925). Occurred during 13 months of the observation period. Monthly incidence higher during comparable months of 1957 than of 1956, except for April. Absence noted during November, December 1956 and January 1957, the period of lowest temperatures (figure 1).

G. simplex. Neritic and estuarine species. Common off west coast of Florida and Galveston, Texas. Observed in Adriatic Sea

(Ercegović, 1936), Plymouth Sound and at Kiel (Lebour, 1925). Appeared at Naples in January and April 1957 at the period of lower salinity and cooler temperatures. *G. simplex* occurred in unusually large numbers (up to 10,000 per ml).

G. breve. Neritic and estuarine species. Observed in an area from Tarpon Springs, Florida, to Ten Thousand Islands off Everglades, and extending 40 miles offshore (Finucane and Dragovich, 1959; Dragovich *et al.*, 1961). Recorded from lagoons near Galveston, Texas. At Naples, present only in low concentrations. Occurred during August and December 1956 and first half of 1957.

Peridinium spp. made up the second most frequently occurring group of dinoflagellates. Frequency of occurrence was considerably higher during 1957 than in comparable months of 1956. Three peridinians were identified to species, *P. divergens* Ehrenberg, *P. depressum* Bailey, and *P. diabolus* Cleve. The identification of *P. diabolus* is questionable.

P. divergens. Neritic species. Observed in Norwegian and Danish seas, English Channel, Adriatic Sea, Bosporus, California (Lebour, 1925), and off Australian coast (Wood, 1954). Common in waters of west coast of Florida; present at Naples in higher numbers only during June 1956 and July 1957. Highest incidence observed during July and August 1957 during a period of low salinities.

P. depressum. Oceanic species. Common in North Sea, Atlantic Ocean, Indian Ocean, and Mediterranean Sea (Lebour, 1925). Observed in Adriatic Sea (Ercegović, 1936), off the east coast of New Zealand (Cassie, 1960), and off the west coast of Florida (BCF; Curl, 1959b). Recorded at Naples during May and September 1956; and June, July, and August 1957. Highest frequency of occurrence recorded during July 1957 at a period of low salinities and great heterogeneity in phytoplankton species composition.

P. diabolus. Oceanic species. Observed in Atlantic, Mediterranean, Plymouth Sound (Lebour, 1925), and off east coast of Australia (Wood, 1954). Occurred at Naples only in small numbers during March and May 1956.

Gyrodinium spp. comprised one of the principal dinoflagellate groups recorded during this investigation. Although found in every month, they occurred more frequently in the samples during 1957 than in comparable months of 1956, except for April.

G. spirale Berg, was the only gyrodinian identified to species.

Known for world wide distribution (Lebour, 1925). Present only during April and May 1956 in minimal numbers.

The genus *Ceratium* Schrank was represented by *C. furca* Ehrenberg, *C. tripos* O. F. Muller, and *C. fusus* Ehrenberg.

C. furca. Neritic species. Observed in northern temperate Atlantic to English Channel, Baltic Sea (Lebour, 1925), Norwegian Sea (Hasle and Nordli, 1951), South Pacific (Cassie, 1960), North Sea (Lucas, 1942), and off the west coast of Florida (BCF; King, 1950; and Curl, 1959b). Occurred during every month of the investigation with the exception of July 1956. Frequency of occurrence higher during 1957 than in comparable months of 1956, appearing in high numbers only during December.

C. tripos. Oceanic species. Observed in North Sea (Lucas, 1942), Norwegian Sea (Hasle and Nordli, 1951), English Channel (Lebour, 1925), South Pacific (Cassie, 1960), and off west coast of Florida. Present at Naples only during August 1957 in small numbers.

C. fusus. Oceanic species. Observed in all oceans (Curl, 1959b). Fairly common in coastal waters of west Florida; occurred at Naples only in small numbers during June, August, and September 1956.

Prorocentrum sp., resembling *P. micans* Ehrenberg, was present during 15 months of this investigation, occurring more frequently in samples during 1957 than in comparable months of 1956. During August 1957, *Prorocentrum* sp. was present in large numbers. The actual count of organisms during these blooms was 100 to 1,000 cells per ml. These blooms occurred in the period of lowest salinities accompanied by high temperatures and high organic phosphate phosphorus content. *Prorocentrum* sp. is common in the coastal waters of west Florida and in East Lagoon, Galveston, Texas.

The genus *Exuviella* Cienkowski was represented by several species, which are listed under *Exuviella* spp. Most of the organisms resembled *E. compressa* (Bailey) Ostenfeld. *Exuviella* spp. were present in small numbers, occurring during 8 months of the observation period. They were recorded most frequently during December 1956 and January 1957. *Exuviella* spp. are common in coastal waters from Tarpon Springs to Cape Sable, Florida.

Peridiniopsis Lemmermann. *Peridiniopsis* spp. occurred through the observation period, but never in high numbers.

Torodinium Kofoid and Swezy. *Torodinium* spp. were never

present in high numbers, but they appeared in the samples during 10 months of the observation period, including January through June of 1957.

Gonyaulax Diesing. *Gonyaulax* spp. were recorded only once during 1956. In 1957, their presence was noted from April until the end of the investigation, a period of reduced salinities. Their highest concentrations were attained in June 1957.

Cochlodinium Schutt. *Conchlodinium* spp. were scarce during 1956. In 1957, they were more frequently observed, occurring during February, April, May, June, and July.

Polykrikos Butschli. *Polykrikos* spp. had a monthly distribution similar to that of *Conchlodinium* spp.

Amphidinium Claparede and Lachmann. *Amphidinium* spp. occurred only from April through July 1957, the period of relatively low salinities, in small numbers.

Dinophysis Ehrenberg. *Dinophysis* spp. occurred in small numbers in October 1956 and July 1957 during the periods of salinity decline. Blooms of *Dinophysis* spp. were recorded in August 1957, when salinity was low.

Dinophysis tripos Gourret. Oceanic form. Observed in Norwegian Sea, Greenland Sea, Indian Ocean, Mediterranean (Lebour, 1925), Australian region (Wood, 1954), and in the coastal waters off west Florida. Rare at Naples, appearing only during October 1956.

Oxyrrhis Dujardin. This genus was represented by one species, which resembled *O. marina* Dujardin, and was very scarce.

Nematodinium Kofoid and Swezy and *Pouchetia* Schutt (emended by Kofoid and Swezy) was represented by a few species. They occurred only during the spring months of 1956 in small numbers.

Two euglenoid groups of organisms and a chrysomonad group, belonging to the family Silicoflagellidae, were also observed at Naples. *Euglena* and *Peranema* first appeared during the spring months of 1957, which were characterized by the onset of the rainy season and a salinity decline. *Peranema* spp. were present in samples from February through April. *Euglena* spp. were observed in March and from May until the end of the observation period. The highest numbers of *Euglena* spp. were recorded during June and July.

After a complete absence during 1956, blooms of silicoflagellates, resembling *Distephanus speculum* (Ehrenberg) Haeck, appeared

in January 1957. Thereafter, although the numerical prominence of these silicoflagellates never attained blooming proportions, they were present in the samples until the end of the observation period.

Unidentified phytoplankton, 5-12 μ in size, were very numerous during every month of this investigation. Most of these cells were generally translucent, yellowish green, somewhat round in shape, and occasionally flagellated. This was the most common group of organisms observed during this study, occurring in 85.2 per cent of observations (figure 2). Despite their minute size, they appear to be a prominent constituent of the plankton.

The most frequently occurring group of ciliates is listed as unidentified species. This assemblage of various species ranged in length from 5 to 80 μ. The smallest organism resembled *Mesodinium pulex* Claparede and Lachmann, while the largest resembled members of the families Frontonidae and Euplotidae. Unidentified ciliates were recorded during every month of the observation period. Consistently high numerical representation was recorded from September 1956 until April 1957 when other ciliates were also prominent.

Vorticella Fromental was the second most frequently observed group of ciliates. Its absence in samples was noted only during June 1956. The highest frequency of occurrence was attained in January. *Vorticella* spp. were most common from July 1956 to May 1957. The shallow investigation area provides an excellent environment for telotrochs and sessile vorticellids.

Tintinnopsis Stein was the third most frequently occurring group of ciliates (figure 2). This genus was present during 14 months of this investigation. Blooms of *Tintinnopsis* spp. were observed during December 1956 and January 1957. These organisms were most common from October 1956 to April 1957. The remaining members of the family were listed as unidentified Tintinnidae. With the exception of March 1956, their presence was observed exclusively during 1957. Their maximum incidence in samples was attained during May 1957.

Ranking fourth in frequency of occurrence among ciliates were the Halteriidae. This group of ciliates occurred more frequently during the comparable months of 1956 than 1957. Blooms were observed during November 1956, and January and March 1957. *Strombidium* Claparédè and Lachmann sp. was the only further identified member of the Halteriidae.

Strombidium sp. occurred in small numbers and was present during the winter and spring months of 1957.

Cothurnia Ehrenberg and *Pleuronema* Dujardin were present only during 1956 in small numbers.

Multicellular plankton, or zooplankton, consisted of copepods, rotifers, ostracods, chaetopods, coelenterates and larval stages of crustaceans, mollusks, annelids, echinoderms, and fishes.

Copepods were very common in samples but never present in high numbers. Their absence was noted only during April and July of 1956. Their maximum frequency of occurrence was observed in March 1957.

Ostracods appeared only during June 1957 and were present in high numbers.

Rotifers, consisting of a variety of species, were listed as unidentified rotifers. They appeared to be a significant segment of multicellular plankton (figure 2), occurring in 26.2 per cent of the samples. With the exception of August, they were noted more frequently during 1957 than in comparable months of 1956. *Synchaeta* Ehrenberg and *Proales* Ehrenberg were listed separately. *Synchaeta* sp. appeared in small numbers and only during August 1956. *Proales* sp. was the only rotifer to attain dense population during this investigation.

Free-swimming coelenterate medusae and echinoderm larvae were very irregular in occurrence, appearing only in small numbers.

Chaetopods, resembling *Dinophilus* Schmidt, were recorded during March, April, and May 1957, a period of high form diversity in other plankton.

Crustacean larvae made up the most commonly observed larval group. Zoea and megalops larval stages were absent only during June and July of 1956. Their frequency of occurrence was greater during the spring months of 1957 than in those of 1956. The temporal occurrence of nauplii was continuous.

Veliger larvae, present during 11 months, never occurred in high numbers. Their frequency of occurrence was greater during 1957 than in comparable months of 1956.

Trochophore larvae were present only during September 1956 in small numbers.

Fish larvae occurred very irregularly during 11 months, always in small numbers.

TABLE 1

Surface Concentrations of Phosphate Phosphorus in Marine Waters

Locality	PO_4-P (μg. at./l) Minimum	Maximum	Mean	Source of Information
South Atlantic Coast of the United States (April 1954)	0.0	1.8	0.3	Anderson and Gehringer (1958)
South Atlantic Coast of the United States (June, July 1954)	0.1	2.4	0.7	Anderson and Gehringer (1959a)
South Atlantic Coast of the United States (September 1954)	0.0	1.4	0.0	Anderson and Gehringer (1959b)
Gulf of Mexico	0.0	5.3	0.2	Collier (1958b)
English Channel	0.03	0.74		Harvey (1957)
Calicut-West Coast of India	0.13	1.68		Subrahmanyan (1959)
Florida West Coast	0.0	2.5	0.3	Finucane and Dragovich (1959)
Florida West Coast	0.0	9.4	1.2	Dragovich, Finucane, and May (1961)
Naples, West Coast of Florida	0.0	3.2	0.6	Present investigation

DISCUSSION

The particular collection and examination method used in the present study permitted the detection of small, fragile forms, including *Gymnodinium breve,* which does not readily survive collection by plankton net or brass water sampling bottle.

King (1950), in his plankton studies of coastal waters of west Florida, observed six diatom genera (*Skeletonema, Navicula, Nitzschia Rhizosolenia, Chaetoceros,* and *Thalassiothrix*) and eight dinoflagellate genera (*Gymnodinium, Gonyaulax, Peridinium, Prorocentrum, Cochlodinium, Polykrikos, Ceratium,* and *Dinophysis*), which we also noted. The same author reported that water samples from river, bay, and coastal areas off Boca Grande, Florida, usually yielded large numbers of *Gymnodinium simplex* when cultured in the laboratory. The present work shows that this organism also occurred in extremely high numbers at Naples. In regard to tintinnids, copepods, ostracods, rotifers, and mollusk larvae, King's observations were in general agreement with our findings. On the other hand, he found much better representation of copepods and diatoms than the fragile phytoplankton forms. He collected plankton with both reversing water bottle and plankton net, preserving the samples in formalin.

For his phytoplankton study of Apalachee Bay and the northeastern Gulf of Mexico, Curl (1959b) detected a greater variety of diatoms than was observed in the present study, but only one nonthecated dinoflagellate. He usually preserved one liter of water with neutralized formalin and concentrated samples in a Forest plankton centrifuge. Ciliates and euglenoid organisms were not mentioned in his report.

The difference between our results and those of Curl and King may be attributed largely to differences in methods of collection and treatment of samples. In regard to detection of non-thecated dinoflagellates, ciliates, and euglenoids, examination of living organisms has advantages over preserved samples. However, this type of sampling method seems not to have any advantage in collection of large multicellular plankton.

Since the author's identifications of most of the plankton were carried out only to family, genus, or listed as unidentified, the plankton probably consisted of a much larger number of species than we list. This should stimulate those who wish to engage in taxonomic plankton studies of the west coast of Florida.

TABLE 2

INCIDENCE OF PLANKTON BY TEMPERATURE INTERVALS

Temperature Range (°C.)	17.0–23.5	23.6–28.4	28.5–31.9
Number of Observations	126	120	120*
UNICELLULAR PLANKTON:			
Amphidinium spp.	0	5	2
Cochlodinium spp.	5	18	10
Gymnodinium breve	3	9	5
G. simplex	2	1	0
G. splendens	9	18	29
G. spp.	89	105	104
Gyrodinium spirale	1	3	0
G. spp.	46	74	53
Torodinium spp.	8	10	5
Polykrikos spp.	7	3	11
Nematodinium spp.	1	0	1
Pouchetia spp.	0	2	0
Oxyrrhis spp.	1	0	0
Ceratium furca	31	18	18
C. fusus	0	3	4
C. tripos	0	0	1
Gonyaulax spp.	1	7	26
Peridiniopsis spp.	7	10	23
Peridinium depressum	2	1	4
P. diabolus	1	1	0
P. divergens	2	5	17
P. spp.	70	74	80
Dinophysis tripos	0	1	0
D. spp.	0	1	6
Exuviella spp.	9	5	4
Prorocentrum sp.	13	32	24
Silicoflagellidae	20	15	11
Euglena spp.	0	6	25
Peranema spp.	4	4	0
Melosira spp.	40	54	38
Skeletonema spp.	0	1	0
Chaetoceros spp.	39	58	86
Guinardia spp.	4	18	6
Rhizosolenia spp.	2	28	9
Thalassiothrix spp.	0	1	2
Navicula spp.	3	6	1
Pleurosigma spp.	1	0	0
Nitzschia spp.	17	30	31

TABLE 2 (cont.)

INCIDENCE OF PLANKTON BY TEMPERATURE INTERVALS

Temperature Range (°C.)	17.0–23.5	23.6–28.4	28.5–31.9
Number of Observations	126	120	120*
UNICELLULAR PLANKTON: (Cont.):			
Grammatophora spp.	1	4	1
Unidentified Phytoplankton	118	120	85
Strombidium sp.	3	3	0
Unidentified Halteriidae	26	28	12
Tintinnopsis spp.	58	42	13
Unidentified Tintinnidae	3	9	31
Vorticella spp.	62	52	33
Cothurnia sp.	1	3	0
Pleuronema sp.	0	1	0
Unidentified ciliates	100	104	68
Coelenterata	1	0	5
Proales sp.	0	1	2
Synchaeta sp.	0	0	1
Unidentified Rotifera	27	42	27
Echinoderm larvae	2	3	2
Veliger	8	11	2
Chatetopoda	0	7	0
Trochophore	1	0	0
Copepoda	27	24	18
Ostracoda	0	1	1
Nauplii	25	26	12
Megalops and Zoea	49	35	21
Pisces larvae	5	5	4
BROAD PLANKTON GROUPS:			
Dinoflagellates	308	406	427
Silicoflagellates / *Peranema* spp.	24	19	11
Euglena spp.	0	6	25
Diatoms	107	200	174
Unidentified phytoplankton	118	120	85
Ciliates	253	242	157
Multicellular plankton	145	155	95

* Number of observations in regard to *Gymnodinium breve* was 125.

Scatter diagrams indicate no correlation between the broad plankton groups (dinoflagellates, diatoms, ciliates, unidentified phytoplankton, silicoflagellates, euglenoids, and zooplankton) and hydrological parameters (temperature, salinity, inorganic phosphate phosphorus, total phosphate phosphorus, nitrate-nitrite nitrogen, carbohydrates, and proteins).

The subtropical annual temperature range of 17.0 to 31.9° C. observed at Naples is comparable to that of Tampa Bay (Dragovich *et al.*, 1961) and to the Apalachee Bay waters of northern Florida (Curl, 1959a). A close parallel between the air and the water temperatures was noted (figure 1). Rapid changes in water temperature occurred during the winter and early spring months but were less pronounced than in Texas bays (Collier and Hedgpeth, 1950) or Tampa Bay (Dragovich *et al.*, 1961). In order to compare the occurrence of plankton constituents with the temperature, the entire temperature data were subdivided into three categories, each of which included about one-third of the total number of observations (table 2). Dinoflagellates, *Euglena* spp., and diatoms occurred more frequently at the higher end of the Naples water temperature range, and the unidentified phytoplankton, ciliates, silicoflagellates, *Peranema* spp., and multicellular plankton were more frequent at the lower end.

Pronounced salinity differences between the relatively dry year of 1956 and the relatively wet year of 1957 were observed. However, the monthly salinity distribution does not show an inverse relationship to the precipitation. This was particularly noticed during November, December, and January. The absence of this relationship may indicate that the waters at Naples are influenced more by the coastal water circulation than by direct fresh-water runoff. The values for Naples show deviation both above and below 35.0o/oo, which may be assumed to be a representative salinity value for the open Gulf. However, the frequency distribution of salinity values showed that in only 6.6 per cent of the observations were the salinities below 35.0o/oo, while in 93.4 per cent of observations they ranged from 35.0o/oo-38.6o/oo, indicating that coastal waters off Naples are marine. The salinity range observed at Naples can be classified as euryhaline (30.0o/oo-40.0o/oo). The temporal salinity distribution indicates that change is more characteristic than steady state for this area. Such changes are typical of coastal waters.

The plankton occurrence was compared with salinities in a manner analogous to the temperature-plankton comparison (table 3). All broad plankton groups occurred with greater frequency at the lower end of the Naples salinity range, with the exception of diatoms and unidentified phytoplankton. A number of taxa, notably several dinoflagellates (including *G. breve*), Tintinnidae, silicoflagellates, and euglenoids, were observed only, or most frequently, in this range.

Higher incidence of certain plankton forms and higher taxonomic diversity of the plankton as a whole occurred during the lower salinity months of 1957 (fig. 3). Abundance of phytoplankton during periods of salinity decline has also been observed in other areas (Bigelow, 1926; Gaarder and Gran, 1927). Dissolved nutrients in land drainage (Wilson and Collier, 1955) and external metabolites (Lucas, 1955; Wilson, 1951; Wilson and Armstrong, 1952) are factors which are thought to be responsible for the greater prominence of plankton at the periods of lower salinity. Thus, salinity reduction *per se* may not have been the decisive factor in proliferation of plankton. However, the salinity tolerances of coastal planktonic organisms observed during this study may have enabled them to take advantage of the availability of nutrients during periods of reduced salinity (Braarud and Rossavik, 1951).

The Florida red-tide organism was never observed to bloom during the period of this study, although the data of Dragovich *et al.* (1961) indicate that *G. breve* occurred in blooming proportions during October and November 1957, in coastal waters less than 8 miles off Naples Pier. The occurrence of *G. breve* was more frequent during 1957 than in comparable months of 1956 (figure 3). In the absence of *G. breve* blooms, the present results do not give evidence of a planktonic succession that may be associated with the development of the Florida red tide. This observation is in agreement with that made by Gunter *et al.* (1948).

The temporal distribution of total phosphorus was characterized by great fluctuations in March and April 1956, and May and June of 1957 (Dragovich, 1961). Possible explanations for the high total phosphorus levels noted are (1) proximity to land drainage outlets, in which high phosphorus concentrations exist, and (2) stirring of the bottom sediment by wind (Harvey, 1957). The absence of an inverse salinity-phosphorus relationship favors the latter possibility. The mean total phosphorus value observed at Naples

TABLE 3

Incidence of Plankton by Salinity Intervals

Salinity Range (o/oo)	32.4–36.0	36.1–36.9	37.0–38.6
Number of Observations	121*	121	115
Unicellular Plankton:			
Amphidinium spp.	5	1	0
Cochlodinium spp.	20	9	2
Gymnodinium breve	9	4	1
G. simplex	1	2	0
G. splendens	19	20	16
G. spp.	107	99	84
Gyrodinium spirale	0	0	4
G. spp.	42	52	71
Torodinium spp.	9	7	5
Polykrikos spp.	12	7	2
Nematodinium spp.	0	1	1
Pouchetia spp.	0	1	1
Oxyrrhis spp.	0	0	1
Ceratium furca	28	27	12
C. fusus	4	2	1
C. tripos	1	0	0
Gonyaulax spp.	25	6	1
Peridiniopsis spp.	13	10	15
Peridinium depressum	4	3	1
P. diabolus	0	1	1
P. divergens	9	5	10
P. spp.	107	74	41
Dinophysis tripos	0	1	0
D. spp.	7	0	0
Exuviella spp.	5	9	4
Prorocentrum sp.	35	24	8
Silicoflagellidae	28	16	0
Euglena spp.	23	5	0
Peranema spp.	4	3	0
Melosira spp.	34	48	44
Skeletonema spp.	1	0	0
Chaetoceros spp.	58	57	65
Guinardia spp.	9	8	10
Rhizosolenia spp.	15	5	14
Thalassiothrix spp.	0	0	2
Navicula spp.	1	6	3
Pleurosigma spp.	1	0	0

TABLE 3 (cont.)

INCIDENCE OF PLANKTON BY SALINITY INTERVALS

Salinity Range (o/oo)	32.4–36.0	36.1–36.9	37.0–38.6
Number of Observations	121*	121	115
UNICELLULAR PLANKTON (Cont.):			
Nitzschia spp.	23	22	30
Grammatophora spp.	5	1	0
Unidentified phytoplankton	83	113	117
Strombidium sp.	4	2	0
Unidentified Halteriidae	40	19	6
Tintinnopsis spp.	45	43	20
Unidentified Tintinnidae	31	7	3
Vorticella spp.	42	60	40
Cothurnia sp.	0	1	3
Pleuronema sp.	0	0	1
Unidentified ciliates	89	93	82
MULTICELLULAR PLANKTON:			
Coelenterata	1	0	4
Proales sp.	1	1	1
Synchaeta sp.	0	0	1
Unidentified Rotifera	46	35	9
Echinoderm larvae	4	2	1
Veliger	10	7	3
Chaetopoda	4	0	0
Trochophore	0	1	0
Copepoda	33	25	6
Ostracoda	0	1	0
Nauplii	23	23	17
Megalops and Zoea	51	34	14
Pisces larvae	8	4	3
BROAD PLANKTON GROUPS:			
Dinoflagellates	462	365	282
Silicoflagellates, *Euglena* spp., *Peranema* spp.	55	24	0
Diatoms	147	147	168
Unidentified phytoplankton	83	113	117
Ciliates	251	225	155
Multicellular plankton	181	133	59

* Number of observations in regard to *Gymnodinium breve* was 126.

Pier was two to three times higher than the corresponding values (0.6 μg.at./l) recorded at the 4-fathom contour off Naples (Finucane and Dragovich, 1959).

The highest inorganic phosphate phosphorus values occurred during March, April, November, and December 1956. The seasonal cycle in inorganic phosphate phosphorus observed in northern latitudes (Harvey, 1957) was not evident. The concentrations of phosphate phosphorus from various marine areas shown in table 1 are comparable to that for Naples. The maximum values observed at Naples exceed all other corresponding values, except those for two other Gulf of Mexico studies.

Concentrations of organic phosphorus were determined by subtracting the inorganic from total phosphate phosphorus, as determined in simultaneously collected samples. Organic phosphorus averaged 45.5 per cent of the total. The concentrations of organic phosphorus varied considerably from sample to sample and showed no consistent change in regard to the inorganic phosphate phosphorus. High values for inorganic and organic phosphorus may also have resulted from the lack of sample filtration.

The temporal distribution of nitrate-nitrite nitrogen was very irregular. The nitrate-nitrite nitrogen data indicate that the levels observed at Naples are very low if compared to certain marine areas such as the English Channel (Cooper, 1937), Sea of Calcutta (Panikkar and Jayaraman, 1953), Gulf of Maine (Rakestraw, 1936), or Barents Sea (Kreps and Verjbinskaya, 1930). Low levels of nitrate-nitrite in the coastal waters of west Florida were also observed by Finucane and Dragovich (1959) and Dragovich *et al.* (1961). Complete depletion of nitrate-nitrites during July, August, and October 1956 may be ascribed to phytoplankton utilization. Nevertheless, scatter diagrams for various groups of phytoplankton and nitrate-nitrite nitrogen show no relationship.

The existence of other chemical factors in the sea, which affect phytoplankton metabolism, has been postulated by various authors (Lucas, 1955; Wilson, 1951; Wilson and Armstrong, 1952; Collier *et al.*, 1953). The concentrations of carbohydrates and proteins in this study showed an erratic distribution. Collier (1958a) postulated that highly uneven distribution of carbohydrates and proteins might be related to the uneven distribution of marine microorganisms (Barnes and Marshall, 1951; Bainbridge, 1953), but scatter dia-

grams for various groups of plankton and carbohydrates and proteins showed no relationship.

This ecological investigation has characterized the shallow coastal waters at Naples as a subtropical, marine environment subject to considerable variation in precipitation and in several ecologically important factors. Dinoflagellates, unidentified phytoplankton, and ciliates were the most prominent representatives of unicellular plankton, and copepods and crustacean larvae were the most frequently observed multicellular plankton. The incidence and population density of *G. breve* were very low. Further taxonomic and quantative plankton work might show more definite relationships between the hydrological conditions and the resident biota.

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SUMMARY

During the course of this investigation, temperature, salinity, total phosphate phosphorus, inorganic phosphate phosphorus, nitrate-nitrite nitrogen, substances which react to the test of arabinose and tyrosine, and plankton composition were determined weekly in the coastal surface waters of Naples, Florida. The temperature variations were characterized by relatively sharp changes from April to May and from October to November. During the remaining months, the temperature changes were gradual. A striking effect of air temperature on water temperature was noted. Marked salinity differences were observed between the summer months of 1956 and 1957.

Phosphate levels were two to three times higher than in the adjacent offshore waters at the 5-fathom curve. Unusually high concentrations of total phosphate phosphorus were noted in May and June 1957, during heavy rainfalls. Nitrate-nitrite nitrogen levels at Naples were low compared with those of other marine areas of the world. The seasonal occurrence of organic substances, which react to the test of arabinose and tyrosine, was very erratic.

The plankton composition consisted of 48 unicellular and 13 multicellular taxa. The unicellular taxa or phytoplankton were represented by 10 genera of diatoms, 26 genera of dinoflagellates

(11 of which were identified to species), a group of unidentified phytoplankton (5-12 μ in size), 2 euglenoid genera, 6 ciliate genera, 1 ciliate family, and a group of unidentified ciliates. Copepods, rotifers, ostracods, chaetopods, coelenterates and larval stages of crustaceans, mollusks, annelids, echinoderms, and fishes constituted the multicellular plankton or zooplankton.

The incidence of plankton was considerably higher during the spring and summer months of 1957 than during the corresponding periods of 1956. This difference is associated with a disparity in rainfall and salinity during the spring and summer months of 1956 and 1957. There was no correlation observed between the various groups of plankton and hydrological parameters.

The particular collection and examination method employed during this investigation seems to have certain advantages over collecting by net and examining preserved samples.

Literature Cited

Anderson, William W., and J. W. Gehringer. 1958. Physical oceanographic, biological, and chemical data—South Atlantic coast of the United States, M/B *Theodore N. Gill* Cruise 6. U. S. Fish Wildlife Serv., Spec. Sci. Rept.—Fish., no. 265, pp. 1-99.

———. 1959a. *Idem,* M/B *Theodore N. Gill* Cruise 8. U. S. Fish Wildlife Serv., Spec. Sci. Rept.—Fish., no. 303, pp. 1-227.

———. 1959b. *Idem,* M/B *Theodore N. Gill* Cruise 9. U. S. Fish Wildlife Serv., Spec. Sci. Rept.—Fish., no. 313, pp. 1-226.

Bainbridge, R. 1953. Studies on the interrelationships of zooplankton and phytoplankton. Jour. Mar. Biol. Assn. U. K., vol. 32, pp. 385-447.

Barnes, H., and M. Marshall. 1951. On the variability of replicate plankton samples and some applications of "contagious" series to the statistical distribution of catches over restricted periods. Jour. Mar. Biol. Assn. U. K., vol. 30, pp. 233-263.

Bigelow, Henry B. 1926. Plankton of offshore waters of the Gulf of Maine. U. S. Bur. Fish. Bull., no. 40, pt. 2, pp. 1-509.

Braarud, Trygve, and Ellen Rossavik. 1951. Observations on the marine dinoflagellate *Prorocentrum micans* Ehrenb. in culture. Avh. Norske Vidensk. Akad., Klasse No. 1, pp. 1-18.

Cassie, Vivienne. 1960. Seasonal changes in diatoms and dinoflagellates off the east coast of New Zealand during 1957 and 1958. N. Z. Jour. Sci., vol. 3, pp. 137-172.

CLEVE, P. T. 1900. The seasonal distribution of Atlantic plankton organisms. Göteborgs Vetensk. Samh. Handl., vol. 17, pp. 1-36.

COLLIER, ALBERT. 1958a. Some biochemical aspects of red tides and related oceanographic problems. Limnol. Oceanogr., vol. 3, pp. 33-39.

———. 1958b. Gulf of Mexico physical and chemical data from *Alaska* cruises. U. S. Fish Wildlife Serv., Spec. Sci. Rept.—Fish., no. 249, pp. 1-417.

COLLIER, ALBERT, AND JOEL W. HEDGPETH. 1950. An introduction to the hydrography of tidal waters of Texas. Publ. Inst. Mar. Sci., vol. 1, pp. 121-194.

COLLIER, A., S. M. RAY, A. W. MAGNITZKY, AND J. O. BELL. 1953. Effect of dissolved organic substances on oysters. U. S. Fish Wildlife Serv., Fish. Bull., no. 84, pp. 167-185.

COOPER, L. H. N. 1937. The nitrogen cycle in the sea. Jour. Mar. Biol. Assn. U. K., vol. 22, pp. 183-204.

CURL, HERBERT, JR. 1959a. Hydrography of the inshore northeastern Gulf of Mexico. Publ. Inst. Mar. Sci., vol. 6, pp. 193-205.

———. 1959b. The phytoplankton of Apalachee Bay and the northeastern Gulf of Mexico. Publ. Inst. Mar. Sci., vol. 6, pp. 227-320.

DAVIS, CHARLES C. 1948. Gymnodinium brevis sp. nov., a cause of discolored water and animal mortality in the Gulf of Mexico. Bot. Gaz., vol. 109, pp. 358-360.

DRAGOVICH, ALEXANDER. 1961. Relative abundance of plankton off Naples, Florida, and associated hydrographic data, 1956-57. U. S. Fish Wildlife Serv., Spec. Sci. Rept.—Fish., no. 372, pp. 1-41.

DRAGOVICH, ALEXANDER, JOHN FINUCANE, AND BILLIE Z. MAY. 1961. Counts of red tide organisms, *Gymnodinium breve*, and associated oceanographic data from Florida west coast, 1957-59. U. S. Fish Wildlife Serv., Spec. Sci. Rept.—Fish., no. 369, pp. 1-175.

ERCEGOVIC, A. 1936. Études qualitative et quantitative du Phytoplancton dans les Eaux cotieres de l'Adriatique Oriental moyen au cours de l'annee 1934. Acta Adriat., no. 9, pp. 1-126.

FINUCANE, JOHN H., AND ALEXANDER DRAGOVICH. 1959. Counts of red tide organisms, *Gymnodinium breve*, and associated oceanographic data from Florida west coast, 1954-1957. U. S. Fish Wildlife Serv., Spec. Sci. Rept.—Fish., no. 289, 1-220.

GAARDER, T., AND H. H. GRAN. 1927. Investigation of the production of plankton in the Oslo Fjord. Rapp. Cons. Explor. Mer, vol. 42, July, pp. 1-48.

Graham, Herbert W. 1954. Dinoflagellates of the Gulf of Mexico. U. S. Fish Wildlife Serv., Fish. Bull., no. 89, pp. 223-226.

Graham, Herbert W., John M. Amison, and Kenneth T. Marvin. 1954. Phosphorus content of waters along the west coast of Florida. U. S. Fish Wildlife Serv., Spec. Sci. Rept.—Fish., no. 122, pp. 1-43.

Gunter, Gordon, Robert H. Williams, Charles C. Davis, and F. G. Walton Smith. 1948. Catastrophic mass mortality of marine animals and coincident phytoplankton bloom on the west coast of Florida, November 1946 to August 1947. Ecol. Monogr., vol. 18, pp. 309-324.

Harvey, H. W. 1957. The chemistry and fertility of sea waters. Cambridge Univ. Press, London, 224 pp.

Hasle, Grethe Rytter, and Erling Nordli. 1951. Form variation in *Ceratium fusus* and *tripos* populations in cultures and from the sea. Avh. Norske Vidensk. Akad., Klasse no. 4, pp. 1-25.

Ketchum, Bostwick H., and Jean Keen. 1948. Unusual phosphorus concentrations in the Florida red tide sea water. Jour. Mar. Res., vol. 7, pp. 17-21.

King, Joseph E. 1950. A preliminary report on the plankton of the west coast of Florida. Quart. Jour. Florida Acad. Sci., vol. 12, pp. 109-137.

Kreps, E., and N. Verjbinskaya. 1930. Seasonal changes in the phosphate and nitrate content and in hydrogen ion concentration in the Barents Sea. Jour. Cons. Int. Explor. Mer, vol. 5, pp. 329-346.

Lasker, Reuben, and F. G. Walton Smith. 1954. Red tide. U. S. Fish Wildlife Serv., Fish. Bull. no. 89, pp. 173-176.

Lebour, Marie V. 1925. The dinoflagellates of the northern seas. Marine Biological Association of the U. K., Plymouth, England, 250 pp.

Lucas, C. E. 1942. Continuous plankton records: Phytoplankton in the North Sea, 1938-39. Part II. Dinoflagellates, Phaeocystis, etc. Hull Bull. Mar. Ecology, vol. 2, pp. 47-70.

———. 1955. External metabolites in the sea. *In* Papers in Marine Biology and Oceanography (Suppl. to vol. 3 of Deep-Sea Res.), pp. 139-148. Pergamon Press, London and N. Y.

Panikkar, N. K., and R. Jayaraman. 1953. Some aspects of productivity in relation to fisheries of Indian neritic waters. Proc. Eighth Pacif. Sci. Congr., vol. 3A, pp. 1111-1122.

Pomeroy, Lawrence R. 1960. Primary productivity of Boca Ciega Bay, Florida. Bull. Mar. Sci. Gulf Caribb., vol. 10, pp. 1-10.

Rakestraw, Noris W. 1936. The occurrence and significance of nitrite in the sea. Biol. Bull., vol. 17, pp. 133-167.

ROCHFORD, D. J. 1951. Studies in Australian estuarine hydrology. Aust. Jour. Mar. Freshw. Res., vol. 2, pp. 1-116, pl. 1.

RUSSELL, F. S. 1939. Hydrographical and biological conditions in the North Sea as indicated by plankton organisms. Jour. Cons. internat. Explor. Mer, vol. 14, pp. 171-192.

SUBRAHMANYAN, R. 1959. Studies on the phytoplankton of the west coast of India. Part II. Physical and chemical factors influencing the production of phytoplankton, with remarks on the cycle of nutrients and on the relationship of the phosphate content to fish landings. Proc. Indian Acad. Sci., vol. 50, pp. 189-252.

WILSON, D. P. 1951. A biological difference between natural sea waters. J. Mar. Biol. Assn. U. K., vol. 30, pp. 1-20, pl. 1-2.

WILSON, D. P., AND F. A. J. ARMSTRONG. 1952. Further experiments on biological differences between natural sea waters. Jour. Mar. Biol. Assn. U K., vol. 31, pp. 335-349.

WILSON, W. B., AND A. W. COLLIER. 1955. Preliminary notes on the culturing of *Gymnodinium brevis* Davis. Science, vol. 121, pp. 394-395.

WOOD, E. J. F. 1954. Dinoflagellates in the Australian region. Aust. Jour. Mar. Freshw. Res., vol. 5, pp. 171-351.

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A Biological Study and Some Economic Aspects of Squid in Tampa Bay, Florida

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Abstract

Distribution of the squid *Lolliguncula brevis* by time and area is described for Tampa Bay and its adjacent waters. Tolerances of *L. brevis* to salinity and temperature are discussed. Particular emphasis is placed upon size at which sexual maturity occurs. A discussion of the economics of the squid fishery is given.

INTRODUCTION

SQUID ARE HEAVILY EXPLOITED for human consumption in many parts of the world (Voss, 1959). Only in recent years has the squid fishery in Florida begun to attract attention. Present catch statistics show evidence of a progressive increase in annual squid landings. In addition to the Florida squid, consisting principally of *Loligo pealeii* and *Lolliguncula brevis,* the fish markets in this state regularly sell *Illex illecebrosus* and *Loligo opalescens,* which are imported from Newfoundland and California, respectively.

Prior to this investigation all published work on squid in the Gulf of Mexico pertained to systematics and geographic distribution (Voss, 1950, 1954, 1955, 1956a and 1956b). Most of Voss' information was based upon material collected by the United States Fish and Wildlife Service Vessel, OREGON. In addition, Gunter (1950) and Tabb and Manning (1961) recorded salinity and temperature ranges and distribution of *Lollinguncula brevis* in the northern Gulf and the waters of Cape Sable, Florida.

Research described in this report was accomplished in connection with an estuarine study of Tampa Bay and adjacent waters. The purpose of this study was to examine the biological, ecological and economic aspects of an animal which appears to be an important member of the estuarine community.

The authors wish to express their appreciation to Dr. Gilbert L. Voss, Institute of Marine Science, University of Miami, for the verification of our taxonomic identifications, advice throughout the course of the study, and review of the manuscript. Randall C. Teague, a summer employee, provided technical assistance and James E. Sykes, Chief of this station, developed portions of the manuscript.

Economic Aspects of Squid Fisheries

While the squid fishery in the Gulf of Mexico is still in its infancy, the annual world catch of all cephalopods is approximately one million tons, or the equivalent of about one pound per man, woman, and child on earth (Lane, 1960).

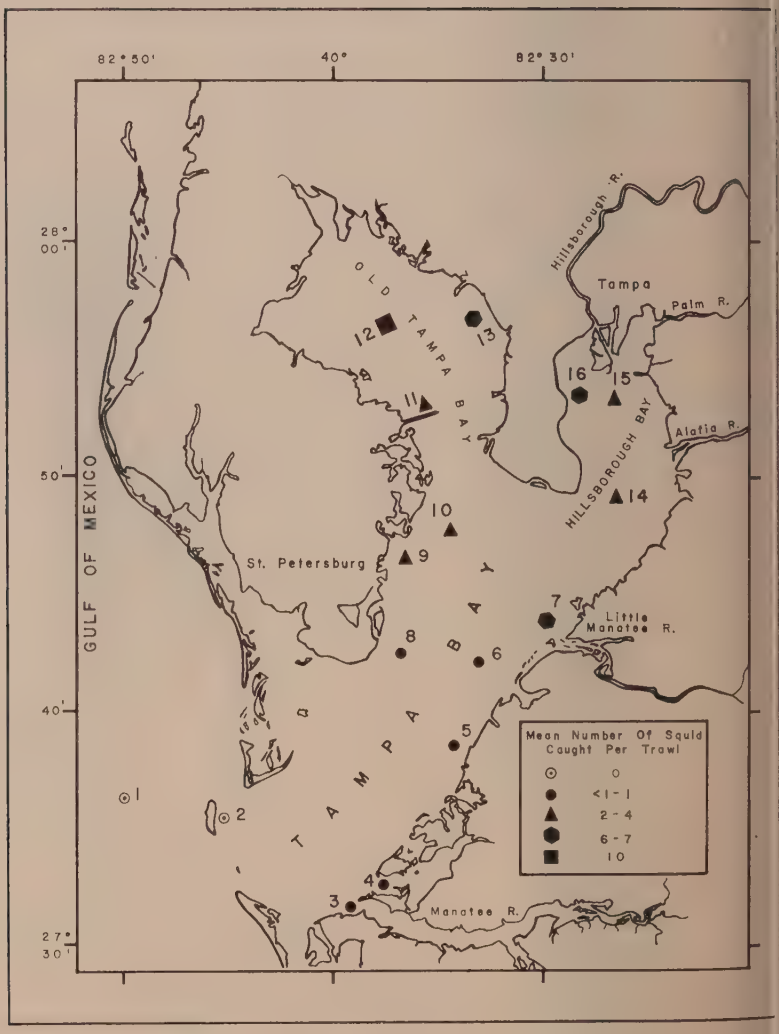


FIG. 1. Tampa Bay sampling stations and distribution of *L. brevis*.

During the period 1953 to 1960, squid represented 6.3 to 9.1% of the report world landings of mollusks. Japan, South Korea, the United States, Spa China (Taiwan), Canada, Italy, and Greece are the leading nations in squ catches, in that order. Japan and South Korea land about 75% of the wo catch. During the period 1953 to 1960, United States fishermen landed 6.1 of the world catch (FAO, 1960).

The oldest and the most productive squid fishery in the United States was established near a Chinese village in Monterey, California (Fields, 1950). The squid fishery in Monterey reached the proportions of a major fishery in 1942. The product is sold within the United States and is also exported to foreign Pacific markets. In 1946 this fishery was valued at $1,214,091, exceeding the value of the sardine catch of the same region. The price of squid varied from $33 to $63 per ton during the period 1935 to 1948. The introduction of lampara nets and modern purse seines, freezing and canning of the catch, and the presence of rich fishing grounds were primary factors in the development of the squid fishery in California.

Although squid are among the most numerous and seemingly inexhaustible animals in the sea, the squid fishery in Florida is still incidental to those for other species. Squid are taken in fish and shrimp trawls. The Florida shrimp fleet takes them in large numbers off Campeche, on the Dry Tortugas grounds, and off Honduras; but they are usually considered trash and thrown overboard (Voss, 1959). Some squid are caught by Tampa Bay fishermen for bait purposes. Despite a progressive trend in squid landings during the past decade, the squid fishery in the Gulf of Mexico still amounts to only $2,000 with a maximum annual landing of 32,000 pounds (U. S. Fish and Wildlife Service, 1960). Florida and Texas are the leading states in squid catches among Gulf States. The first official squid landings by Alabama and Louisiana were recorded in 1960. At present Mississippi is the only State in the Gulf not reporting squid landings.

These statistics are no reflection of the consumption and market demand for squid and perhaps not even of availability. The annual consumption of squid in the Tampa Bay region alone far exceeds the entire annual landings by the Gulf States. Most of these squid are imported from California and from Atlantic coast states. Squid are retailed in markets at 29 to 39 cents per pound. A single fish market on the Gulf beaches of St. Petersburg, Florida, buys 10,000 pounds of squid annually. This is more than the combined annual landings by all Gulf States. In addition to utilization as fish bait, squid are consumed in the Tampa Bay area for human food. They taste somewhat like scallops or abalone and besides being nutritional are a gastronomic delicacy. The food value of the common Japanese squid when seasoned and canned (Tanikawa, 1952) is as follows: food energy, 117 cal/100 g; crude protein, 13%; fat, 1.83%; and carbohydrates, 7.11%.

Squid is a food of many commercially important fishes. In a study of bigeye and yellowfin tuna in the Pacific Ocean, King and Ikehara (1956) found that the food of these fish by volume consisted of 29% squid for yellowfin tuna and 33% squid for bigeye tuna. Squid consumed by these fish were of the families Loliginidae and Ommastrephidae.

There are about 57 species of squid in the Gulf of Mexico (Voss, 1956b). *Doryteuthis pealei*, the common squid, and *Lolliguncula brevis*, the brief or thumstall squid, have potential commercial importance in the Gulf area. The geographic distribution of *L. brevis* includes the Gulf of Mexico; the Atlantic coast of the United States from Maryland to Florida; the Caribbean Seas; and the Atlantic coast of South America to Rio de Plata. Distribution of *L. pealei* is similar except that on the Atlantic coast it extends from New England to Florida.

Field Procedure

Biological Study

Sixteen stations, located in Tampa Bay and adjacent waters, were sampl with a ten-foot shrimp try-net (Fig. 1). Sampling was conducted from the search vessel, KINGFISH, a 43-foot, twin-screw, diesel cruiser, and from sixteen-foot outboard motor boat.

Sampling was scheduled on a weekly basis during September, October, a November, 1961. From December, 1961, through August, 1962, all tra were made on a bi-weekly basis. Trawling speed was maintained at 3-4 kn for a 10 minute period at each station. All field collections of squid w preserved in 10% formalin. Subsequently, the specimens were soaked in t water and then transferred to 70% alcohol.

Concurrent with biological collections, temperature and salinity determi tions were made. Water samples for salinity determinations were collected w Van Dorn bottles (Van Dorn, 1957) or weighted polyethylene containers. containers used for storage of samples were chemically cleaned prior to u Water temperature was obtained with a Whitney underwater thermome (model T65) and recorded to the nearest tenth of a degree Celsius. Salin was determined by the Mohr-Knudsen method as described by Knudsen (190 and recorded to the nearest hundredth of a part per thousand.

Laboratory Procedure

EXTERNAL EXAMINATION: The dorsal length of all animals was measured fr the anterior margin of the tip of the rostrum to the posterior end of the dors (Fig. 2). These and all other measurements were made with the aid of Vern calipers and recorded in millimeters. Mantle length is equivalent to stand length and was used throughout this paper simply as body length. T is considered a basic measurement for comparative purposes by all teu ologists (Voss, 1956; Fields, 1950; and Lane, 1960). The mean body leng respective standard deviation, and coefficient of variation were determi for each category of sex and maturity. Weighing of entire animals or of cert organs was made with a Mettler analytical balance. All squid were examin for the presence of a hectocotylized arm. Once this arm has been develop external identification of the male sex is possible.

INTERNAL EXAMINATION: The maturity stage and sex were classified for ea specimen by internal examination of reproductive organs. Prior to this exa ination, the entire ventral portion of the mantle was removed to facilitate spection of the organs.

Each specimen was classified in one of three categories: immature-unsex immature-sexed (male or female), or mature (male or female). If neither pe nor nidamental glands were visible, the animal was labeled "immature-unsexe In specimens identified as males the spermatophoric sac was dissected a spermatophores, if present, were examined under the microscope. If sperm tophores possessed a distinctly developed head, spiral tube, cement gland, a sperm sac, the animal was considered mature (Fig. 2). In some males with well developed penis, the spermatophoric sac was either empty or the sperm tophores, if present, were not fully developed. These were classified as "imn ture-sexed (male)." Female squid were considered mature if ova approximat 2 mm in diameter were found in the oviduct (Fields, 1950). When ova

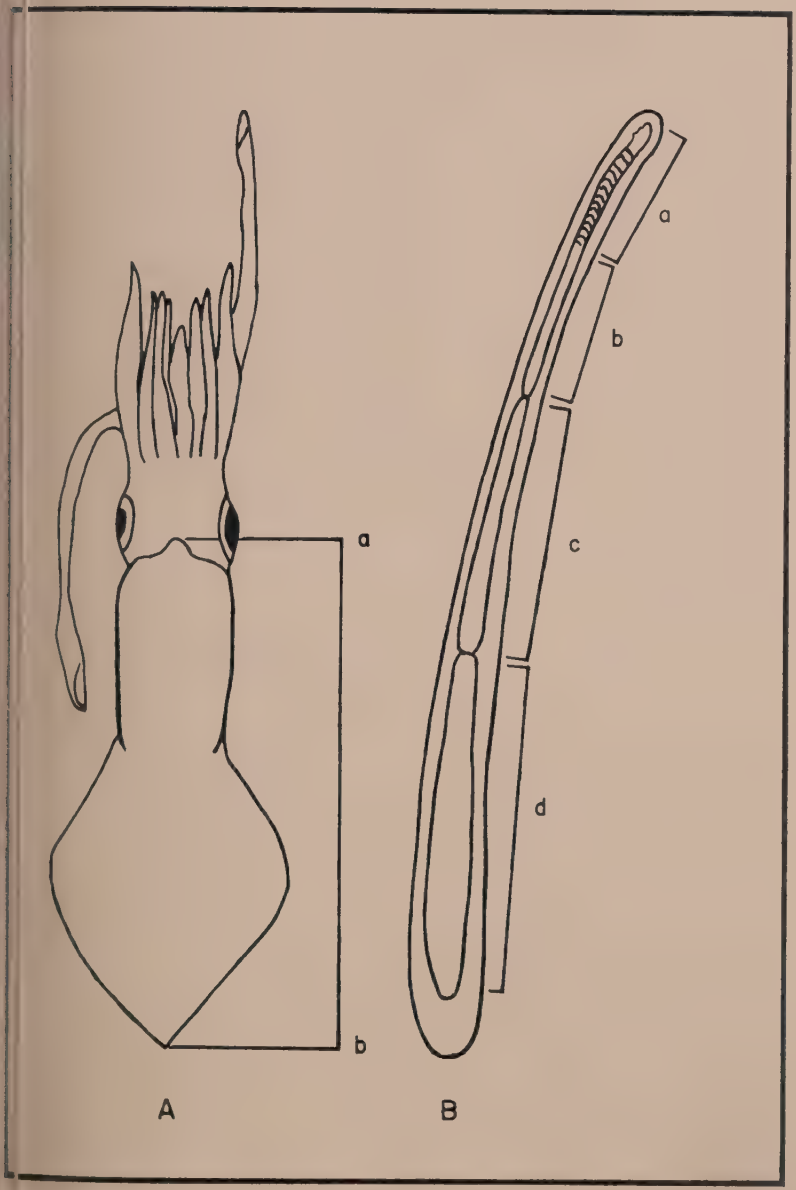


Fig. 2. A-Dorsal view of a squid illustrating the mantle length measurement, and B-Mature spermatophore (X 29); a-head or horn; b-tube; c-mid section or cement gland; d-sperm reservoir.

proached this size, they were translucent and yellowish-orange in color. If the were no ova or if all of them were less than 2 mm in diameter, the specim was said to be in the "immature-sexed (female)" category. Although the co dition of nidamental glands was not used as a criterion of maturity, examinati showed that in mature specimens the glands were large, firm, white, and occ pied the entire, upper-ventral half of the mantle cavity (Fig. 3).

In examining reproductive organs, attention was focused on the macrosco appearance of the organs and surrounding viscera. This was done to relate t macroscopic changes in reproductive organs to the body length of the orga isms, and to pave the way for more detailed microscopic studies which m be accomplished at a later date. Examinations were facilitated by the fact th all collected animals were in excellent condition.

RESULTS

Distribution: All squid collected during this investigation were of the sa species, *Lolliguncula brevis*. Numerically, *L. brevis* was the second most abu dant invertebrate observed in trawl collections, and represented 13.4% of collected organisms. From September, 1961, through August, 1962, 378 tra were made in Tampa Bay and adjacent neritic waters. The average number squid per trawl varied from 0 to 9.7.

Squid abundance as measured by catch per trawl was greater in the up estuary than in the lower estuary (Fig. 1). Old Tampa Bay was the most p ductive subarea, contributing 42.8% of the combined catch. Percentages the total catch by other areas were 25.3% in Hillsborough Bay, 30.4% central Tampa Bay, and 1.5% in lower Tampa Bay. At all sampling static *L. brevis* was dominated by immature organisms. Squid were not caught at t mouth of Tampa Bay or in adjacent Gulf of Mexico waters.

The seasonal occurrence of squid was characterized by maximum tra catches in late summer and early fall and irregular catches during the rema ing portion of the observation period (Fig. 4). Both mature and immatu squid occurred throughout the study except during the month of July wh mature animals were absent.

The maximum water temperature (32C) during the sampling period w observed in July in central Tampa Bay and the minimum (12.6C) was record in January in Old Tampa Bay. During the summer and early fall mont temperature variations seldom exceeded IC. Cooling during the fall mon proceeded slowly (Table 1). The monthly mean temperature did not fall bel 20C until December. The water warmed progressively from February to Ju when the maximum was reached. Monthly water temperature was closely as ciated with air temperature.

The range of salinity measured concurrently with squid sampling extend from 17.32‰ during August in Hillsborough Bay to 35.66‰ in July, 3 miles offshore in the Gulf. A horizontal gradient was present throughout t observation period with the maximum zone in the adjacent Gulf waters a minimum zone in the upper portion of the estuary (Table 1). Monthly salin changes were associated with fluctuations in rainfall. A reduction in salin was particularly noticeable from June through August during the period high rainfall. The monthly salinity variations in offshore waters did not para those in Tampa Bay.

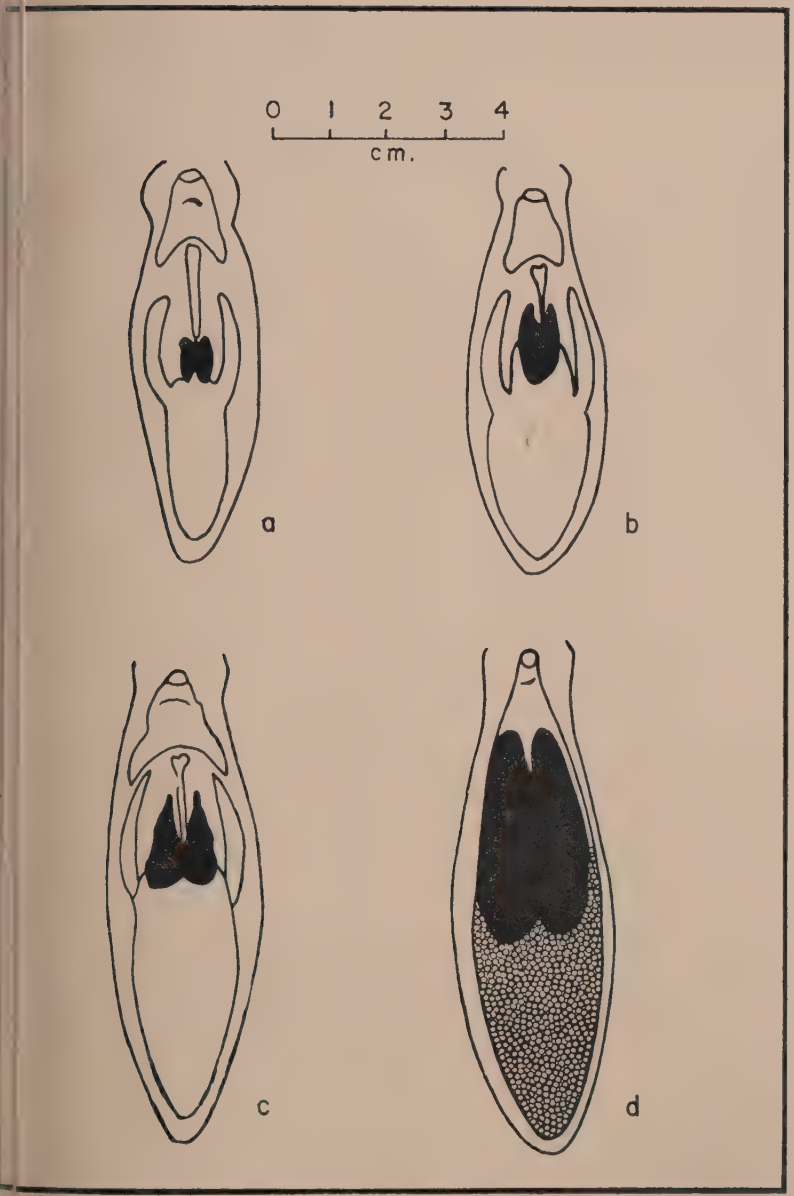


Fig. 3. Nidamental glands increasing toward maturation. The dark central region shows nidamental glands; a- and b- immature specimens; c- approaching maturity or in puberty stage; d- nidamental glands and eggs in mature specimen.

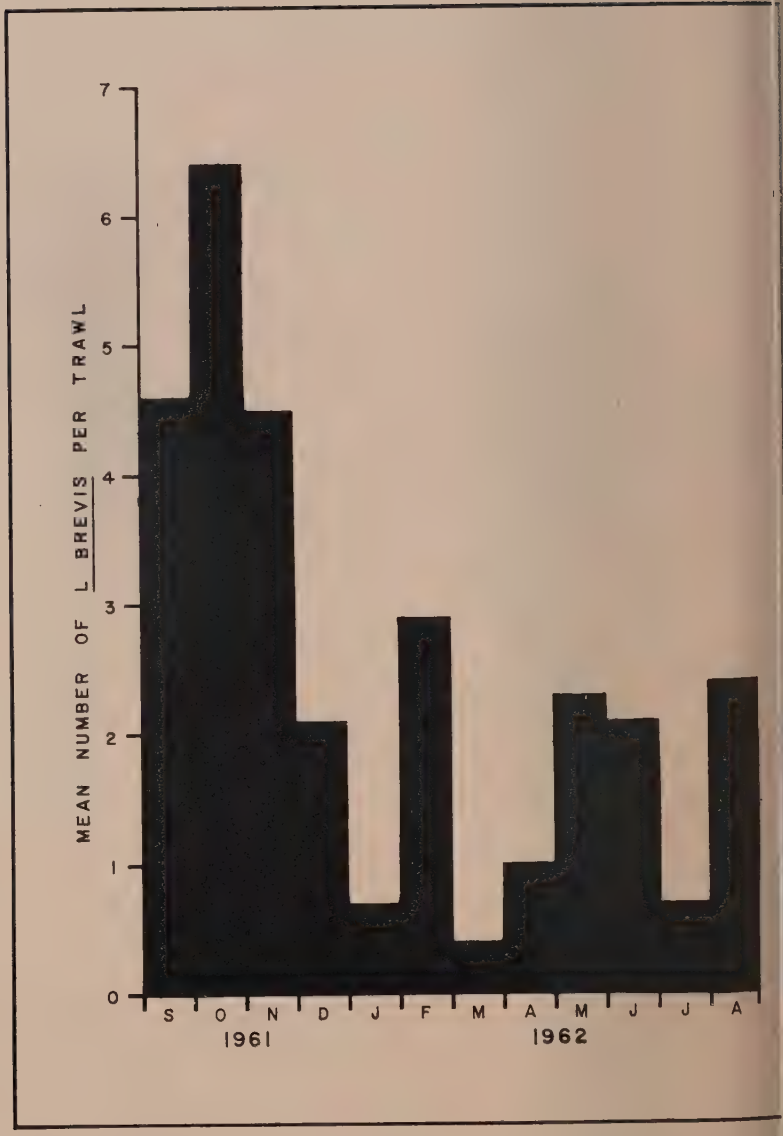


FIG. 4. Monthly occurrence of *Lolliguncula brevis* in Tampa Bay, Septemb
1961 - August, 1962.

Sex and Maturity: The sex ratio of total squid collected was 1.12 males per female; of mature squid, 7.1 males per female; and of immature squid, 1.1 males per male. Male squid were more abundant than females at a majority of stations.

A large portion (36.3%) of specimens were in the immature-unsexed category. The organisms in this group varied in body length from 8.0 mm to 40.0 mm with a mean of 18 ± 4.7 mm. The body length of the majority (87.5%) of unsexed squid was found to vary between 8 mm and 28 mm (Fig. 5).

Fifty-six percent of all examined organisms were in the immature-sexed category. The body length of immature males varied from 16 mm to 75 mm (Fig. 5). The majority of immature males (83.7%) were within the narrow range in body length of 18 mm or between 21 mm and 38 mm. Only 3.5% of the specimens were less than 21 mm in body length while 12.8% were larger than 38 mm. The mean length of all immature males was 30.1±7.5 mm. Immature females had the widest range in size. The body length in this group varied from 17 mm to 86 mm with a mean of 34.7±12.1 mm. The largest portion of immature females was between 22 mm and 41 mm in body length and constituted 78.3 percent of all immature females. Only 4.5% were smaller and 17.2% were larger than the extremes in this range.

The smallest proportion (7.7%) of males and females was observed in the mature category. The frequency distribution of these specimens was irregular (Fig. 5). Mature males ranged in body length from 32 mm to 83 mm and the mean was 54.4 ± 12.4 mm. The body length of mature females ranged from 74 mm to 107 mm and the mean length was 87.1 ± 5 mm.

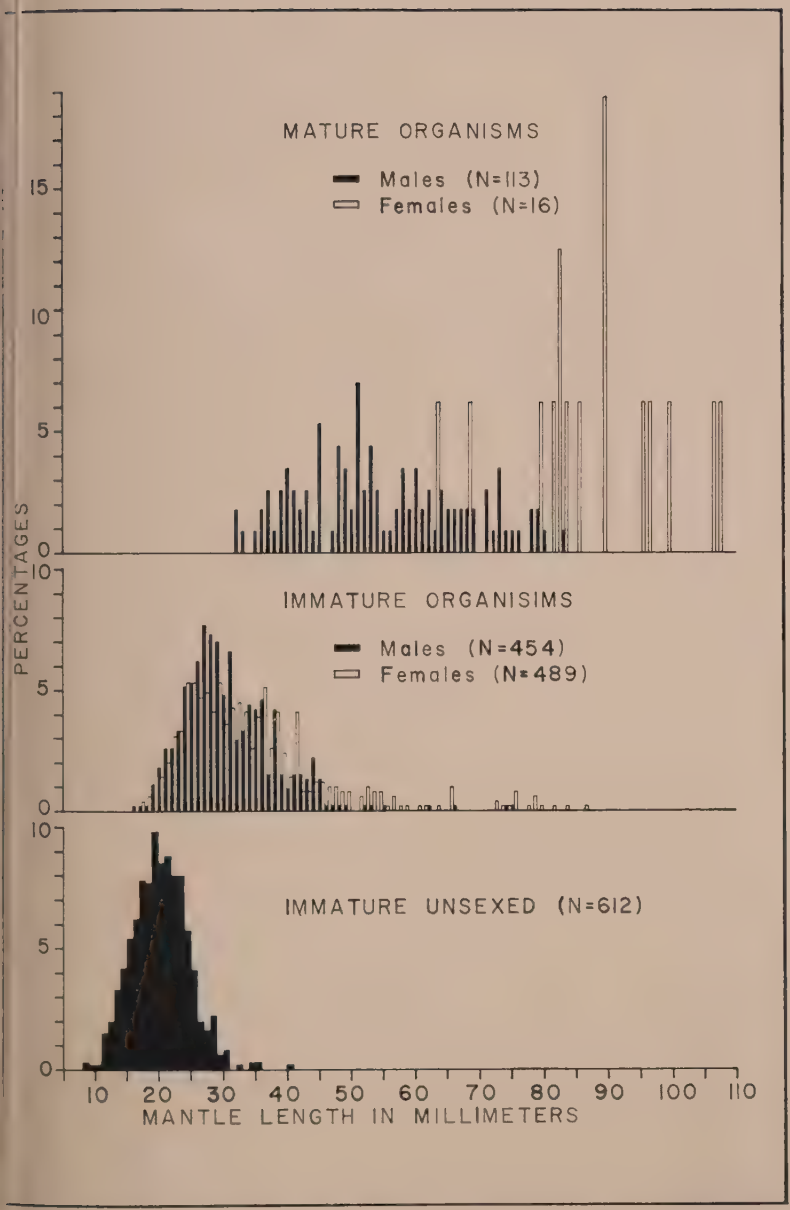
Condition of Reproductive Organs in Relation to Body Length: The first sexual manifestation in males is the development of a penis. Smallest specimen having a penis was 18 mm in body length. The length of the penis varied from 1 mm to 14 mm. The second observed sexual manifestation in males is the development of spermatophores. Immature males in the puberty stage ranged from 20 mm to 74 mm body length. This stage was characterized by the presence of immature spermatophores and included 15.6% of the males examined. The majority (76%) of squid in this stage was found within a range of 24 mm to 38 mm body length, while 8.4% and 15.5% were below and above this range, respectively. The number of spermatophores in the puberty stage varied from one to six. The size of the spermatophoric sac in this stage is relatively small, usually 5 mm to 10 mm in length. Following puberty the spermatophores mature and at this time squid reach their full reproductive capacity. The size of the spermatophoric sac becomes relatively large and is filled with spermatophores stored neatly in spaghetti-like fashion. Counts among ten, randomly selected, mature males showed that the number of spermatophores was not related to size of the animal. The length of mature spermatophores varied from 4.9 mm to 7.1 mm. The weight of the entire reproductive system accounted for 1.4 to 1.5% of the total body weight. Body length of the ten randomly selected animals varied from 65 mm to 75 mm.

The first external appearance of secondary male characteristics was evident at 20 mm body length. In 97% of the specimens, development of the hectocotylized arm was observed at sizes about 30 mm. In 84% of the animals with the hectocotylized arm, mature spermatophores were present. In the remaining 5.6%, spermatophores were immature or absent.

TABLE 1

MEAN TEMPERATURES, RAINFALL AND SALINITIES IN TAMPA BAY, FLORIDA
SEPTEMBER, 1961 - AUGUST, 1962

Location	1961				1962							
	S	O	N	D	J	F	M	A	M	J	J	A
Water Temperature (°C)												
Hillsborough Bay	27.9	24.7	22.0	19.2	16.7	18.2	19.4	22.0	26.8	28.5	30.2	29.0
Old Tampa Bay	27.1	24.2	21.9	18.2	16.4	19.9	17.0	23.2	26.7	29.1	30.5	29.4
Central Tampa Bay	27.9	24.7	22.7	18.9	16.0	18.1	18.2	20.2	26.4	28.8	30.6	30.1
Lower Tampa Bay	27.3	24.3	22.5	18.2	16.4	19.7	17.5	20.8	24.7	28.8	30.5	30.5
3½ miles offshore	27.7	24.6	22.8	19.0	15.6	-	19.0	19.7	23.8	28.8	30.7	30.5
Air Temperature (°C)												
Old Tampa Bay	27.7	23.6	21.0	17.9	15.8	19.3	17.7	20.8	25.5	26.6	28.3	27.7
Rainfall in Inches												
Old Tampa Bay	2.43	0.25	0.94	3.80	1.40	0.40	4.26	1.43	2.76	6.34	2.31	10.14
Salinity (‰)												
Hillsborough Bay	24.88	27.07	28.91	28.50	27.75	27.68	27.87	27.57	28.78	28.84	25.32	23.92
Old Tampa Bay	24.24	25.28	26.92	28.24	27.75	27.99	28.43	28.41	29.92	29.53	28.87	26.91
Central Tampa Bay	27.63	29.13	30.56	30.60	29.89	28.53	29.90	29.90	30.99	30.58	29.29	28.35
Lower Tampa Bay	30.92	31.92	32.59	32.76	31.86	-	32.31	31.82	34.10	33.07	32.12	29.99
3½ miles offshore	34.96	34.45	33.84	33.96	33.36	-	34.29	34.07	35.59	35.39	35.76	35.01



IG. 5. Frequency distribution of mature and immature *Lolliguncula brevis* each millimeter range of mantle length, shown as percentage of the total umber of squid in each stage of maturity (Tampa Bay, September, 1961 - Au-ust, 1962).

Although nidamental glands were not used as indicators of maturity, t dissection of females revealed that sexual development is accompanied by distinct increase in size of the glands (Fig. 3). The earliest macroscopic ev dence of a nidamental gland was noted in a specimen 17 mm in body lengt In most squid ranging from 20 to 60 mm body length, the development nidamental glands appeared to be a gradual process. From 60 mm to 86 m this development occurred rapidly. Above 86 mm all specimens were ful mature.

The nidamental glands in immature specimens varied in length from 1.0 m to 17 mm. Comparable dimensions for the mature females were 22.8 mm ar 36.5 mm. In mature specimens the whole reproductive system, including ov extended from the anterior to the posterior end of the mantle cavity (Fig. 3 The weight of the reproductive organs in five fully mature females accounte for 23-26% of the total body weight.

Egg counts were made in three randomly selected mature females. Eg counts and body lengths were 1,400; 1,700; 3,900 and 63, 85, and 107 m respectively. The largest eggs averaged 2 mm in diameter, while the smalle in the same organism averaged 1 mm in diameter. In the female with 3,90 eggs, there were 750 eggs averaging 2 mm in diameter and 3,180 eggs averagin 1 mm in diameter. The proportion between the two sizes of eggs was specif for each observed specimen.

Stomach Contents: Examination of stomachs revealed that 80% of the were empty. The highest percentage (94%) of empty stomachs occurred i organisms less than 40 mm in body length. In the remaining 6%, the stomac contents consisted of mud particles only. In organisms larger than 40 mm bod length, 54% of the stomachs were empty. Taxonomic identification of stomac contents was not possible in most instances, because the material was severel mutilated and fragmented. Even though the squid is carnivorous, small fra ments of *Gracilaria verrucosa*, *Thalassia testudinum*, and *Spyridia* sp. wer identified. The anterior half of a *Limulus polyphemus* larva was also observe in one of the stomachs. The remaining material was taxonomically unidentif able and consisted of various parts of planktonic crustaceans, fish scales, fis eggs, bits of flesh, and sand or mud particles.

DISCUSSION

The examination of macroscopic changes in reproductive organs disclose the sizes of *L. brevis* at which maturity occurred. It was shown that male mature at smaller sizes than females. The male may become mature at a lengt of 32 mm or may remain immature until it reaches 75 mm in body length Comparable sizes for females are 63 mm and 86 mm respectively. The larges immature female (86 mm) was 3 mm longer than the largest mature male The range of body length in the group of unsexed specimens indicates tha the development of reproductive organs does not occur at any particular size In all specimens less than 17 mm in body length, the macroscopic identificatio of sex was impossible.

The largest specimen of *L. brevis* observed during this study was about on third shorter than the maximum size (150 mm) observed by Tabb an Manning (1961). Since 1.6% of all collected squid were greater in length tha 75 mm, we doubt that our collecting gear was adequate in capturing the fas

swimming, larger specimens. The findings with regard to the larger specimens should, therefore, be considered preliminary.

The dispersion of body length in relation to its mean, measured as the coefficient of variation, was greatest in immature females (34.9%). The coefficient of variation for immature males was 10% lower than that for immature females. In organisms with undetermined sex the coefficient of variation was 27%. The least variation in body length was observed in mature organisms. The variation in mature females (5.7%) was smaller than in males (22.8%).

The first macroscopic appearance of primary sexual characteristics, penis in the male and nidamental glands in the female, occurred in both sexes at about the same body length. The secondary sexual characteristics were observed only in males. The presence of the hectocotylized arm in males was an indication of sex only, not of maturity. Simultaneous presence of mature and immature eggs in mature organisms indicated that the maturation of eggs is a gradual and continuous process, once the organism reaches maturity (Clark, 1962).

The stomach analysis revealed that *L. brevis* exceeding 40 mm body length fed upon planktonic crustaceans and fish. The data also suggest that organisms smaller than 40 mm may utilize mud particles as a source of food.

To compare the possible influence of temperature and salinity on the occurrence of *L. brevis*, both were subdivided into three ranges, each of which included about one third of the total number of observations (Fig. 6).

L. brevis occurred with greatest frequency in the lower portion of the salinity range and decreased in frequency as salinity increased. To check the occurrence of *L. brevis* in extremely low salinities, trawl activity was extended during August to the mouth of the Alafia River, a tributary of Tampa Bay. One immature specimen was found at a salinity of 2.40‰, the lowest at which a squid was recorded. Salinities at which squid were observed by Hunter (1950), Tabb and Manning (1961), and Haefner (1959) were 17.7‰, 5‰ to 38‰, 28.6‰, and 29.4‰. Thus, *L. brevis* may be considered a euryhaline organism at least in immature stages. The data do not permit determination of whether salinity, *per se*, is the decisive factor in areal and seasonal distribution of squid. However, the ability of *L. brevis* to tolerate low salinities enables them to inhabit upper and lower portions of the estuary. Thus, *L. brevis* is available as food to other animals with great salinity tolerances as well as to those restricted to a narrow range in salinity. The estuarine nature of *L. brevis* is unique since most of the cephalopods are exclusively marine.

In relating temperature to the occurrence of *L. brevis*, it was noted that the animal occurred most frequently at the intermediate temperature range and less frequently at the lower end of the temperature scale than at the higher end. These observations are in general agreement with those of Tabb and Manning (1961).

The numerical dominance of immature-unsexed squid over those that were mature suggested local spawning. In one instance, newly hatched squid were observed during September in Old Tampa Bay.

The best tangible evidence of spawning time is the occurrence of ripe egg masses and the developmental stages of newly hatched organisms. Fields (1950) found that in *Loligo opalescens* large reserves of spermatophores and ova were found throughout the year and, with the exception of freshly exhausted organisms, the accessory organs were maintained in potential spawning conditions

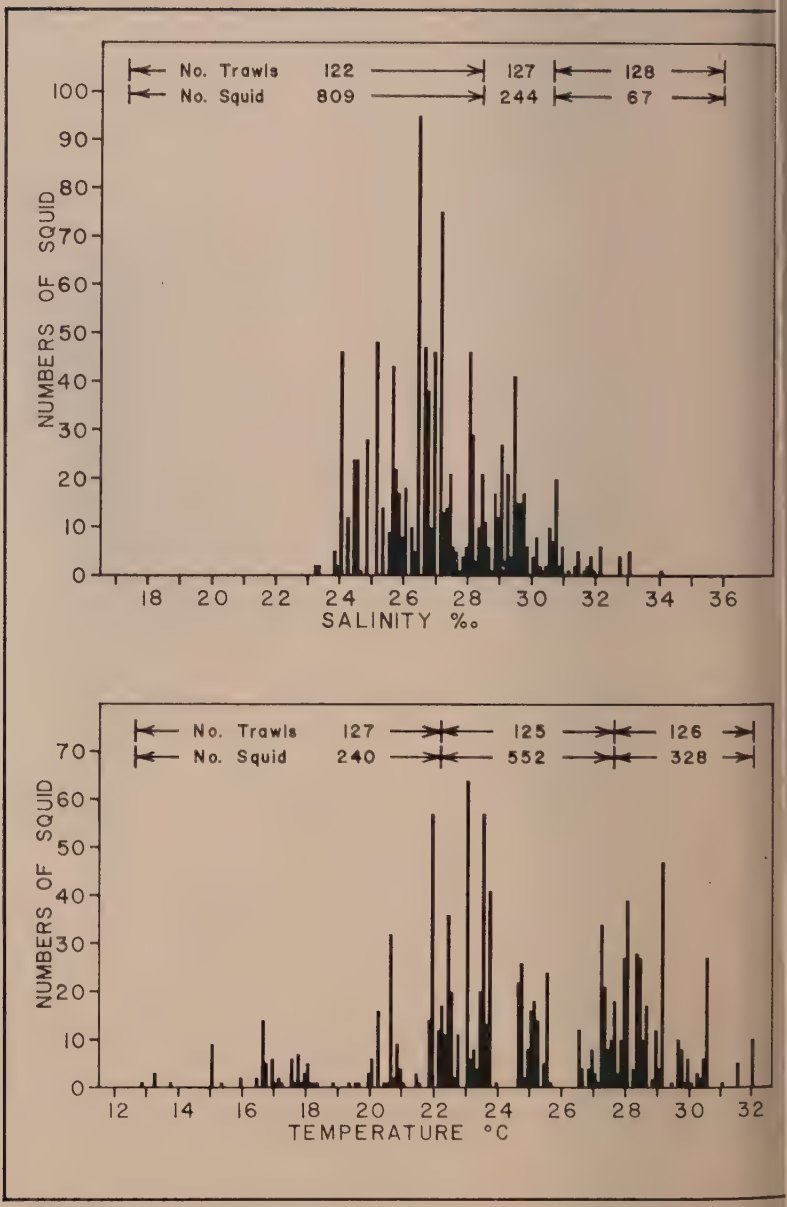


FIG. 6. Incidence of *Lolliguncula brevis* in Tampa Bay at three salinity an temperature intervals, each of which includes a comparable number of ob servations, September, 1961 - August, 1962.

all times. He reported further that squid spawned on every occasion when introduced into an aquarium at Hopkins Marine Station, California. Since collections included some ripe organisms throughout the most of the year, specific spawning season was indicated. The findings, therefore, are in general agreement with those of Fields (1950).

At present there is no estimate of the availability of squid stocks to the commercial fishery industry of the Gulf States. Furthermore, this is an incidental fishery and little attention has been paid to its development. It appears that the domestic market is ready to absorb much larger quantities of squid than the amount being produced by local fishermen. The foreign market has a pressing demand for protein and appears capable of increasing its consumption of squid. In consideration of these potential markets, experimentation with fishery methods seems advisable and could result in increased efficiency of exploitation.

LITERATURE CITED

Clarke, Malcolm R.

1962. A large member of the squid family Cranchiidae, *Phasmatopeis cymactypus* de Rochebrum, 1884. Proc. Malec. Soc. London, *35* (1): 27-42.

Fields, W. G.

1950. A preliminary report on the fishery and on the biology of the squid, *Loligo opalescens*. Calif. Fish and Game, Hopkins Mar. Sta. of Stanford Univ., Pacific Grove, Calif. *36* (4): 366-377.

Food and Agricultural Organization of the United Nations

1960. Yearbook of Fishery Statistics. XII : c-67 through c-72.

Gunter, G.

1950. Seasonal population changes and distribution as related to salinity, of certain invertebrates of the Texas coast, including the commercial shrimp. Publ. Inst. Mar. Sci. (Univ. Texas), *1*(2): 7-51.

Heffner, P. A., Jr.

1959. Morphometry and biology of *Loligo pealei* Lesueur, 1821 and *Lolliguncula brevis* (Blainville, 1823) in Delaware Bay. M. S. Thesis, Univ. of Dela. 61 p.

Ing, J. E. and I. I. Ikehara

1956. Comparative study of food of bigeye and yellowfin tuna in the Central Pacific. U.S. Fish and Wildl. Serv., Fish. Bull. *57*(108): 61-85.

Knudsen, M.

1901. Hydrographical tables. G.E.C. Gad, Copenhagen, 63 p.

Lane, F. W.

1960. Kingdom of the octopus. The life history of the cephalopoda. Published by Sheridan House, New York, 300 p.

Lobb, D. C. and R. B. Manning

1961. A checklist of the flora and fauna of Northern Florida Bay and adjacent brackish waters of the Florida mainland collected during the period July 1957 through September 1960. Bull. Mar. Sci. Gulf and Carib., Contr. No. 354, The Mar. Lab., Univ. of Miami, Fla. *11*(4): 552-649.

Tanikawa, E.

1952. Studies on the complete utilization of the squid (*Ommastrephes sloani pacificus*). Bull. Fac. Fish, Hokkaido *3*(1): 73-94.

U. S. Fish and Wildlife Service

1960. Fishery Statistics of the United States, 1960. Statistical Digest No. 53: 529 p.

Van Dorn, W. G.

1957. Large-volume water sampler. Trans. Geophy. Un. *37*(6): 682-684.

Voss, G. L.

1950. Two new species of cephalopods from the Florida Keys. Revista de la Sociedad Malacologica Carlos de la Torre, Contr. No. 39, The Mar. Lab., Univ. of Miami, Fla. *7*(2): 73-70.

1954. Cephalopoda of the Gulf of Mexico. U.S. Fish and Wildl. Serv., Fish. Bull. *55*(89): 475-478.

1955. The cephalopoda obtained by the Harvard-Havana expedition off the coast of Cuba in 1938-39. Bull. Mar. Sci. of the Gulf and Carib. Contr. No. 142, The Mar. Lab., Univ. of Miami, Fla. *5*(2): 81-115.

1956a. A checklist of the cephalopods of Florida. The Quart. Jour. Fla. Acad. Sci. Contr. No. 164, The Mar. Lab., Univ. of Miami, Fla. *19*(4): 274-282.

1956b. A review of the cephalopods of the Gulf of Mexico. Bull. Mar. Sci. Gulf and Carib. *6*(2): 85-178.

1959. Potentialities for an octopus and squid fishery in the West Indies. Proc. Gulf and Carib. Fish. Inst., Twelfth Ann. Sess., Contr. No. 257, The Mar. Lab., Univ. of Miami, Fla., p. 129-135.

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Report on the New Albatross IV

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NEW ERA in fisheries-oceanographic research will soon begin with the commissioning of the ALBATROSS IV. The new vessel has been built to serve the research needs of the Bureau of Commercial Fisheries Biological Laboratory Woods Hole. It is one of several new vessels to be built by the Bureau to assist in meeting the pressing demands for a better understanding of oceanic resources.

The ALBATROSS IV perpetuates an illustrious name in the annals of marine research that started with the steamer ALBATROSS, launched in 1882. It was the first vessel built especially for marine research by any government, and like the Woods Hole Laboratory, it was originally conceived by Spencer F. Baird. For forty years it provided a platform for biological and oceanographic research from the North Atlantic to the North Pacific.

The ALBATROSS II was a converted Navy tug. It served the purpose of Wallford, Bigelow, Herrington, and many other well known marine biologists in the New England area for six years prior to 1932 when it was inactivated.

The ALBATROSS III, also a conversion, was used for fishery research in the New England area from 1948 until 1959. Much of this research was concerned with the problems of the International Commission for the Northwest Atlantic Fisheries. This research made possible the regulation of the cod and haddock populations and generally advanced our knowledge of the techniques of fishery management. Particularly, it made possible the planning of a more profound study of the ocean environment when funds became available for a new and truly efficient and flexible research vessel.

Following long and careful consideration of the requirements for their new vessel by the Woods Hole staff, the ALBATROSS IV was designed by Dwight S. Simpson and Associates, Marine Architects and Engineers of Boston, Massachusetts, to meet these requirements.

It is a unique vessel in a great many ways, being designed for completely modern and efficient fishery-oceanographic research. It is, for example, the first stern trawler to be constructed in the United States. Vessels with similar stern ramps have been used for many years now by various European countries, usually a few, however, with movable gantries. The gantry is hydraulically con-

trolled to move fore and aft through an arc of 115°. It can literally transpo apparatus weighing up to 10,000 pounds from the surface of the water aste to a position well forward on the stern deck. Its principal functions will inclu handling fishing nets, bottom dredges, heavy bottom samplers, and similar ge

The new vessel is unusually maneuverable. Precision research frequent requires the exact positioning of the vessel with regard to bottom topograph currents, wind, and so forth. ALBATROSS IV can literally move sideways again a considerable wind. This is accomplished through the combined action of t bow thrust engine and the Kort nozzle. The Kort nozzle replaces the conve tional rudder, and is essentially a movable tube enclosing a variable pit propeller.

The double-drum, main-trawl winch is located out of the way on the low deck. Each drum holds 6,000 feet of ⅞-inch diameter cable with a lev mechanism that can be adjusted for various wire sizes. The drums are driv through a reduction gear by a 125 h.p. electric motor to develop a stalled li pull of 30,000 pounds on both warps. From the winch, the warps run forwa and up to a pair of 20-inch sheaves on the main deck and aft to the towi blocks just inside the throat of the gantry. The warp from the dredging winc with 4,000 feet of ⅝-inch cable, is led in a similar manner along the midli of the vessel. The winch is equipped to handle conductor core cables.

FIG. 1. The first stern trawler to be built in the U. S. A. The fishery - oce ographic vessel ALBATROSS IV will be operated by the U. S. Bureau of C mercial Fisheries, Woods Hole, Mass.

The sheaves on the main deck for the trawl and dredging winches are vered by a 36-inch high counter which also supports a vertical capstan and a all winch with 100 feet of ½-inch cable at each end.

The main boom is set on the mid-line of the ship at the forward end of the ning deck. It will lift 10,000 pounds at a 34-foot radius and has two sets falls, each with its own winch. On each mast there is a 24-foot steel pipe om with powered falls and hand operated vangs. The control station for the in trawl winch, dredging winch, the main boom vangs, and the two fall nches on the boom is located at the after end of the boat deck just to starard of the center line. From here, the winch operator has a clear view of the entire fishing deck.

At the after end of the boat deck, on the port side, there is an articulated draulic crane which can reach down to the water line, pick up a 1,000-pound ad and deposit it on either the main deck or the boat deck anywhere within 13-foot radius of its base. There are two hydrographic winches on the after d of the boat deck as well, each with a capacity of 20,000 feet of ¼-inch re. Collector rings are provided for five electrical conductors. The control nsole is on the end of a 20-foot extension cable so that each winch can be erated either at the winch, at the rail, or on the main deck.

A watertight well, 5 by 6 feet wide, for servicing transducers, runs from the ain deck down to the bottom of the ship. At the bottom, on each side of the el there are hinged, watertight doors that hold the sounding transducers. The nsducers can be changed or serviced at sea by putting a man in the well, mping in air until sufficient pressure is created to prevent flooding, and then ening the lower doors. In addition are two instrument wells, one in the wet boratory and another in the hydrographic laboratory. These are approximately ree and a half feet square and can be opened or closed by a diver or can be ed to put divers in the water.

Salt water is supplied to the wet laboratory, the rough laboratory, and the hing deck by a non-corrosive, non-toxic system. The suction is located so at the entering sea water is not contaminated from any of the ship's discharges.

The arrangement of the laboratory spaces was carefully designed to provide od communication between them as well as with the rest of the ship, but at e same time to keep them separate from the traffic of people engaged on her business. As little of the furniture and equipment as possible is permaently fastened to the ship's structure so as to permit easy rearrangement to eet the needs of the future.

Just forward of the fishing deck, open aft and on both sides, but sheltered the house forward and the deck overhead, is a 32- by 10-foot area designed r the preliminary processing of the collections. There is a bathythermograph inch with 2,000 feet of 3/16-inch wire with its own hydraulic "A" frame at ch rail. A dumb-waiter communicates with the storage room on the lower ck and up to the boat deck, to facilitate the transportation and storage of ecimens and supplies.

Forward of the rough laboratory on the port side is the 13-foot by 33-foot et laboratory, divided into two separate spaces by a movable bulkhead. acilities include a wet gear locker, dumb-waiter to decks below and above, nks, salt water tables, work benches, overhead cabinets, refrigerator, and orage lockers. Every 3 feet along the permanent bulkheads are outlets for 110

volt alternating current, compressed air, cold salt water, hot fresh water, a
cold fresh water.

Forward of the rough laboratory on the starboard side is a 10-foot squ
hydrographic laboratory for the immediate processing of water samples. It
Nansen bottle racks, storage cabinets, work bench, sink, and desk. Over
desk is an instrument panel giving time, ship's heading and speed, water de
wind direction and velocity, air temperature, relative humidity, sea surf
temperature, and barometric pressure. The indicating and recording unit for
telerecording bathythermograph is also visible from the desk. Communicat
with the hydrographic laboratory is a 7- by 13-foot space for chemical analy
It is equipped with a sink, work bench, cabinets, freezer, salinometer, a
spectrophotometer.

Forward of the chemistry laboratory, the dry laboratory, 11 by 15 feet, l
a drafting table, desks, a work table, cabinets, typewriter, and calculators. H
the asdic and 6,000-foot sounder signals can be displayed on a precision grap
recorder for study and analysis.

There is a 10- by 12-foot laboratory on the after part of the boat deck
tended primarily for underwater television research, and the monitoring, ma
tenance, and repair of specialized electronic equipment. It has work bench
cabinets, cable ports, four kinds of electric power, and a dumb-waiter co
municating with the main and lower deck. Like all other laboratory spaces
can be readily converted to other purposes.

The after 50 feet of the lower deck is a single large compartment. Both o
board bulkheads are lined with bins for fishing gear and shelves and cabin
for sample containers. The trawl winch and dredging winch occupy the cen
of the room. Aft of the winches there is an elevator set under a flush hatch
the trawl deck to move heavy gear between the two decks. A walk-in refrige
tor and a freezer are at the forward bulkhead.

Forward of the engine room are six cabins for scientists, one of which me
the requirements for a hospital room. Each cabin has three berths, locke
bureau, and lavatory. These facilities, as others, can be expanded to carry
larger crew if so required.

This is but a brief resume of the facilities and equipment of the ALBATR
IV. At the moment, perhaps its best feature is that it is capable of sever
challenging an experienced fishery scientist to realize its full potential as
scientific tool.

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OBSERVATIONS ON THE SMALL MAMMALS OF THE SOUTHEASTERN SHORE OF HUDSON BAY

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THIS REPORT IS BASED on trips made in 1950, 1953, and 1954 to Hudson Bay and Richmond Gulf. The first, an ecological reconnaissance of the Richmond Gulf area (Edwards and Chamberlin, 1951), was financed by the American Philosophical Society; and the second, during the summer of 1953 (Edwards and Chamberlin, 1962), to investigate the hydrobiology of southeastern Hudson Bay and Richmond Gulf, was financed jointly by the American Philosophical Society, the Woods Hole Oceanographic Institution, the Geological Society of America, and the American Academy of Arts and Sciences. The research was continued in the summer and fall of 1954 with funds obtained from the Arctic Institute of North America.

Dr. J. Lockwood Chamberlin* was my partner on all of these trips. His interest was the invertebrate marine fauna and the hydrography of the area. My father, Robert D. Edwards, accompanied us on the first leg of the 1953 trip.

We made the trip to Richmond Gulf in 1950 on board the M/V *Fort Charles* through the courtesy of the Hudson's Bay Company. The 1953 and 1954 trips were made aboard our own research vessel, the R/V *Lemming*, a thirty-foot ex-shrimper.

From the viewpoint of a mammalogist, the summer of 1950 was desolate around Richmond Gulf, following as it did the die-off of the rodent population of the previous fall. We spent two weeks circumnavigating the area that season, trapping (over 900 trap-nights) wherever we stopped. Not a single microtine was seen or caught. The loneliness of the land was relieved only by the presence of a few red squirrels, a porcupine and a weasel. However, numerous skeletons of mice and large scat piles pointed to a large rodent population during the previous summer.

Although the rodents were numerous in 1953, an expected peak year of the four-year cycle, our success in collecting small mammals was less than we had hoped. The difficulties of doing hydrographic work from a small boat in Hudson Bay, under generally adverse weather conditions, severely limited our opportunities to work on land. Whenever the opportunity presented itself, we went ashore to set traps and make observations of the rodents. By standing quietly we could usually see several moving about and feeding, where in 1950 not a single microtine was to be seen or trapped.

We named our anchorages and prominent features of the landscape. It should be emphasized here that many of these names do not have any official

*Presently with the Bureau of Commercial Fisheries Biological Laboratory, Washington, D.C.

sanction. Such unofficial geographic references are indicated by an asterisk when used for the first time.

Subspecific designations have not been attempted, pending further study with more extensive material than is presently available from the entire northern Quebec area. The bulk of the material has been deposited in the Museum of Comparative Zoology, Harvard University.

AREAS INVESTIGATED

Each of the areas trapped is described briefly below. A short description of the plant life is included. For further detailed information on the plants and plant associations, the reader is referred to Marr (1948), Hustich (1951), and Dutilly and Lepage (1951).

Merry Island (*55°22'N, 77°45'W*). The southernmost island of the Manitounick Peninsula (see inset, Figure 1) is a tilted thrust block with the high steep face on the sound (east) side. This topography is typical of the Hudson Bay coast from here on to well north of Richmond Gulf. A canyon-like cut runs through the island a short distance north of the tip. The distinctive green aspect of this cut, with its small spruce forest, completely isolated from the mainland and from similar plant communities along the island chain, attracted our attention late in the afternoon of August 23, 1953.

The cove at the end of the cut was small with a relatively rocky beach. Above the strandline was a broad zone of the grass *Elymus arenarius*. Beyond this there was an extensive area of shrubs and forbs, including *Salix* (several species), *Juniperus*, *Betula*, *Vaccinium*, *Arctostaphylos*, several species of *Carex*, *Solidago*, *Potentilla*, and *Saxifraga*. Farther back of this where sufficient sandy soil existed, was the spruce *Picea mariana*. The ground cover in the spruce was composed to a great extent of lichens and mosses, with *Cornus canadensis*, *Ribes glandulosum*, *Linnaea borealis* and *Empetrum nigrum* in patches and individually. On the rocky talus areas a more typical tundra flourished, composed largely of many kinds of reindeer mosses, with *Vaccinium Vitis-ideae*, *Empetrum* and *Dryas integrifolia* in abundance. A substantial growth of dwarf *Betula* and *Salix* species occupied the lower parts of the talus slopes.

Twenty-five traps were put out just before dark, in a line running through all of the above-mentioned plant communities. Shortly after dark the trapline was checked and when five *Phenacomys* were found to be trapped, principally in the drier portions of the talus, ten more traps were put out in this area. The traps were removed the following morning when we departed.

**Three Islands Harbor* (*56°07'N, 76°04'W*). The trapping was done on the westernmost of three small islands that form a protected anchorage in the southeastern part of Richmond Gulf. A narrow band of *Elymus* with an admixture of *Ligusticum scothicum* bordered the strandline on the harbor side, followed by a substantial growth of alder (*Alnus arctica*), and succeeded in turn by a dense thicket of small spruce where the slope steepened. Near the top of the island, where it leveled out, a typical reindeer moss tundra, with a scattering of *Vaccinium uliginosum* and *V. Vitis-ideae*, *Epilobium*, *Ledum*, *Salix reticulata* and other dwarf willows, was followed by the bare rock top

FIGURE 1. Map of Richmond Gulf area indicating localities mentioned in text.

A trapline of thirty traps was set out for two nights on the evening of August 29.

**Papp's Cove* (*56°06'N, 76°04'W*). This large cove in the southeastern corner of Richmond Gulf is the site of the Hudson's Bay Company store and the Roman Catholic Mission. Until 1954, a free trader, Mr. George Papp and his wife lived there. Mr. and Mrs. Papp are well known for their many kindnesses to the various investigators who have worked in and around Richmond Gulf.

Near the trading post, at the north end of the beach, was a flat, lush, grassy area. A series of broad, poorly defined terraces extended back to bare rounded hills about a mile to the rear. The level portions of the terraces were

covered with a mixture of lichens and forbs typical of the area. The slopes of the terraces had a luxuriant growth of *Betula glandulosum* which extended a variable distance out onto the terraces below. A small creek, called Beach Creek locally, bisected the terrace series. Its steep banks were covered with alder and spruce. Where the terraces adjoined the hills, spruce was usually abundant. *Larix* and *Alnus* occurred with the spruce. Some of the common flowering plants of the area were *Solidago multiradiata*, *Rhinanthus oblongifolius*, *Epilobium latifolium*, *Aster puniceus*, *Linnaea borealis* and *Cornus canadensis*.

Thirty-five traps were put out here late in the afternoon of September 23.

**Golfcourse Cove* (*56°17'N, 76°30'W*). This was a large, well-developed raised beach series at the end of a cove on the western side of Richmond Gulf. The usual grass zone with *Lathyrus japonicus* following the beach gradually gave way to a typical lichen tundra admixed with *Arctostaphylos*. *Vaccinium uliginosum* and *V. Vitis-ideae*, *Tanacetum huronense*, *Artemisia borealis*, *Salix vestita*, and *S. arctica* occurred in patches on the level portion of the terraces. The slopes of the terraces generally had considerable *Betula glandulosum* on them. On either side of the terraces, near the cliffs with their talus, various arctic forbs abounded. A small stream ran down through this terrace series with a considerable growth of alder along its bank at the lower end. While we were here, a series of bad storms made it hazardous to row ashore from the boat. As a result, only one trapline of thirty traps was run and this on the night of September 10.

**Sculpin Cove* (*56°08'N, 76°33'W*). I trapped (300 trap nights) this area for several days during the 1950 trip but secured no mice. On September 25, 1953, ten traps were placed in a broad, dense growth of alder and willow along a small stream, while fifteen were placed in a relatively luxuriant growth of spruce. The traps were pulled early the following morning when we departed.

ABUNDANCE

In 1950, over 600 trap nights of effort were expended in the Richmond Gulf area, without effecting the capture of a single vole or lemming. Red squirrels were observed in fair number wherever the spruce was well developed and specimens were secured without difficulty. One varying lemming was observed running across an open area in the spruce at Great Whale River. However, the evidence of a high population the previous year in the form of carcasses, skeletons, scat piles, grass cuts, and so forth, was everywhere to be observed.

In 1953, on the other hand, the voles especially abounded and were easily captured and readily observed. The captures obtained are listed in Table 1. A comparison of these data with those of Smith and Foster (1957) for the Churchill area on the other side of Hudson Bay would suggest that the small mammals on the east coast reached a higher density more quickly, both populations being at a low level in 1950 or 1951. Although I was unable to complete the 1954 trip and repeat the small mammal survey, Chamberlin (*personal communications*) reported that the small mammals were still in evidence during

TABLE 1.—Small mammal captures with snap-traps in 1953. Trap lines visited once late at night and in morning

Species/No. trap nights	Merry Island	Three Island's Harbor	Papp's Cove	Golfcourse Cove	Sculpin Cove	Total
	35	60	35	35	25	190
Sorex cinereus	—	—	2	1	—	3
Clethrionomys gapperi	6	23	10	8	5	52
Phenacomys ungava	9	15	9	4	5	42
Microtus pennsylvanicus	2	12	8	1	3	26
Synaptomys borealis	6	11	2	4	2	25
Dicrostonyx hudsonius	1	5	—	2	—	8
Peromyscus maniculatus	2	—	—	—	—	2
Capture totals	26	66	31	20	15	158

the late summer and fall. It therefore seems apparent that there is no definitive four year cycle as far as the microtines, at least, are concerned.

PREDATORS

Foxes, *Vulpes vulpes*, were seen on Weston Island in the south central part of James Bay but nowhere else. A striking number of Short-eared Owls, *Asio flammeus*, and Rough-legged Hawks, *Buteo lagopus*, were observed. Every cliffside bordering on tundra or spruce harbored at least one pair of Rough-legged Hawks and their offspring. Short-eared Owls were frequently observed flying at dusk, particularly at Richmond Gulf, in groups of five or six. The owl pellets found contained the skulls and bones of *Phenacomys* and *Microtus*.

SPECIES ACCOUNTS

The following annotated list includes notes on all species observed and/or collected. No effort was made to capture all possible species in the area. We attempted, within the limitations of time, to observe what we could of the voles and lemming, and to determine their relative density.

Fleas were collected and identified by the author. To avoid straggling, each mammal species was transported and kept in separate cloth bags until the specimens could be examined.

Mean measurements are given, followed by extremes in parentheses. Standard length measurements are given to the nearest millimeter. Weight is in grams.

Condylura cristata (Linnaeus) STAR-NOSED MOLE

A skin of the star-nosed mole was obtained from Mrs. George Papp. Her eskimo dog had caught the mole the previous year behind her house. This is the most northerly record to date, although it seems reasonable to predict that *Condylura* may eventually be collected in the Fort Chimo area.

Sorex cinereus Kerr COMMON CINEREOUS SHREW

Three specimens of the cinereous shrew were collected in the Richmond Gulf area, one in the *Elymus* zone at Golfcourse Cove, the other two in the alders and dwarf birch at Papp's Cove.

Average measurements of three adults (no sex) are: total length 95 (90-105); tail 40

(37-42), hind foot 11 (11-12); weight 3.5 (1 specimen).

Mustela erminea Linnaeus SHORT-TAILED WEASEL

An adult male weasel was collected at Papp's Cove, July 25, 1950, by Andrew, an Indian boy. It measured as follows: total length 310; tail 93; hind foot 43; testes 8; and weight 170.

Another weasel was observed the same month near a small stream where I was fishing. I had laid a sizable char behind me on the bank when the weasel appeared and attempted to make off with the fish. This, despite the fact that the fish weighed 13 pounds. The weasel retreated, squeaking angrily, when I approached.

A skull of this species was picked up in the surf at Golfcourse Cove.

Lutra canadensis (Schreber) OTTER

Seeing my labors stuffing mice, an old Indian brought me a peculiar specimen of mammal that he had prepared himself. It was made up like a museum study skin and stuffed with dried moss. He had trapped a female otter that April (1950) near Richmond Gulf and stuffed up one of the unborn young.

Phoca vitulina True HARBOR SEAL

The harbor seal was seen from time to time in Richmond Gulf, less frequently along the coast of Hudson Bay itself. It is, of course, much sought after by the Eskimos of the area for food and clothing.

Erethizon dorsatum (Linneaus) PORCUPINE

Porcupines were not observed often although they were in evidence in the better-developed stands of trees. One specimen was collected at Sculpin Cove in 1950, a female, measuring as follows: total length 686; tail 127; hind foot 89.

Marmota monax (Linnaeus) WOODCHUCK

Several skins belonging to Mrs. Papp were examined. Indians infrequently catch woodchucks in the interior behind Richmond Gulf.

Tamiascuirus hudsonicus (Erxleben) RED SQUIRREL

During the 1950 trip we spent several days in the Sculpin Cove area, living in what remained of the Gulf Lead Mines cabin. Red squirrels were frequently seen in the nearby spruce; it was possible to walk to within a few feet of them without their showing much fear. The squirrels spent much of their time on the ground and in burrows under and around the spruce. Middens were found infrequently and they were not especially large. We searched for but did not find any nests in the trees.

Each of the red squirrels captured carried a few fleas, *Orchopeus caedens* (Jordan) in every case.

The average measurements of two adult females are: total length 310; tail 116; hind foot 47; weight 200.

Clethrionomys gapperi (Vigors) GAPPER'S RED-BACKED VOLE

The red-backed vole was abundant in the spruce thickets and under the denser and wetter cover of shrubs. Considering the relative proportions of the various plant communities further inland, the red-backed must have been the most abundant small rodent in boreal Ungava during the summer of 1953 if our experience was any criterion (cf. Cameron and Morris, 1951). With the exception of *Dicrostonyx* it was the only species that went consistently for the bait. The red-back did not make any obvious runs, but a trap by any likely looking hole in the moss of the spruce groves, or in a cavity under the roots of a spruce, or under a thicket of alder, birch or *Ledum*, or down deep between rocks in a cavity in the forest would get one every time.

Our first experience with this mouse was in a Hudson's Bay Company warehouse while we were outfitting the R/V *Lemming* at Moosonee. Four were taken here and only one had the typical red-back coloration. The other three were colored much like No. 6 in Bang's plate (1897), although a bit darker. All of those collected on Merry Island were normally colored. Three of twenty from Three Islands Harbor were gray-brown. All those collected behind Papp's were typical but for one completely black specimen. Of five from the south side of the terraces at Golfcourse Cove, one was dark brown and another black, while those from the talus on the north side were all yellowish brown and so different in general appearance that it was hard to believe that they were red-backs. The speci-

mens from Sculpin Cove were all typical. Most of the normally colored red-backs at Richmond Gulf had an unusually intense yellow coloration on the belly.

There was no evidence of any current breeding activity at Spruce Canyon, Papp's Cove, or Sculpin Cove. At Three Islands Harbor, the adult females were all lactating and their uteri were swollen, although none were carrying embryos. The female red-backs at Golfcourse Cove also had internal evidence of recently completed breeding, the males all had partially enlarged testes, 4 mm on the average, that were ascending or had ascended. More immatures were collected here than anywhere else. Very few mice that could be definitely assigned to the previous season were captured.

All stomachs examined contained finely chewed green plant matter, and the contents of many were colored a dark blue presumably from the berries of *Vaccinium uliginosum*. There were considerable cut pieces of *Ledum palustre* about the haunts where red-backs were trapped at Three Islands Harbor.

Trapped specimens of red-backed mice usually carried a few fleas each of two species, *Malaraeus penicilliger dissimilis* Jordan and *Monopsyllus quirini* (Rothschild).

The average measurements of 17 adults (9 males, 8 females) are: total length 162 (150-170); tail 44 (38-47); hind foot 19 (18-20); weight 37 (23-49).

Phenacomys ungava Merriam HEATHER VOLE, PHENACOMYS VOLE

The heather vole was the commonest rodent in the particular areas we visited. *Microtus* was similarly abundant, but only in the restricted zone of grass above the shoreline. Many were caught in the talus, in hollows in the tundra and under the dwarf trees where no discernible pathways could be seen (Figure 2A). The majority were caught on the shallow, broad but not obvious runs that connected patches of cover or ran from the spruce forest out onto the open areas. A single nest containing an immature female was found under a large, flat rock a scant twenty feet from the water's edge at Three Island's Harbor (Figure 3). The voles were frequently observed during daylight hours storing the stems of *V. Vitisideae* in shallow burrows (old lemming burrows apparently) and under rocks in the open flat areas, cf. Foster, 1961, p. 193 (Figure 2B). These stems, from three to six inches long, were cut at the base and stored intact, leaves, stem, berries and all. There were no nests connected with these caches. It was not apparent that the voles were interested in the berries, although they were plentiful and ripe. The stomachs examined all contained finely chewed green plant material. *Aster puniceus* was common at Three Island's Harbor, and in those areas where there were many *Phenacomys* it was usually badly cut up, presumably by this species.

The voles apparently breed through the month of August. All the males caught after this time had ascending or ascended testes. One female from Merry Island had embryos, R1L3 2 mm. Several females from this locale and from Three Islands Harbor had recently given birth. The number of truly immature individuals captured seemed unusually small, despite the fact that the voles were still breeding when we first got to Hudson Bay.

Fleas, *Monopsyllus a. asio* (Baker), were found occasionally on trapped specimens.

The average measurements of 18 adults (8 males, 10 females) are: total length 143 (131-161); tail 32 (26-38); hind foot 18 (16-20); weight 40 (29-54).

Microtus pennsylvanicus (Ord) PENNSYLVANIA MEADOW VOLE

Excluding those taken on the islands in James Bay, all the meadow mice collected may be provisionally referred to *Microtus pennsylvanicus labradorius* Bailey. The fully adult animals tend to be large, up to 180 mm in total length and weighing as much as 76 grams. Their coloration is paler than typical *M. pennsylvanicus*, homogeneous on the sides and dorsum, belly typically pale gray. There is an obvious yellow-brown spot on either side of the muzzle.

In the summer of 1953, *Microtus* was abundant everywhere we went, especially in the grassy, wetter areas. The runs were used so frequently and by so many mice that in many places they were beaten more than an inch into sandy soils (Figure 2C). In some places, where it was estimated that the numbers exceeded two hundred individuals per acre, no nests could be found. Around the buildings at Richmond Gulf, the mice occupied every discarded can and

were to be found under almost any board, under drums of gas, in pipes, in fact under or in anything that offered protection. In those places bordering on water, where a relatively narrow strip of grass was backed up with alders, the grass zone was riddled with runs, and broader runs could be seen leading into the alders. Presumably the mice had burrows and nests amongst the shrubs, but none could be found. The mice were rare or not present within the spruce forests, nor were they taken on the tundra. They were caught, however, in a most barren talus slope at Golfcourse Cove.

Meadow vole scat piles were distinctively bright green and so constantly trodden upon that the scats were coalesced into homogeneous masses. They varied in size from small piles to masses five or six inches in diameter and an inch or so thick.

Occasional specimens of *Microtus* were caught with one or two fleas on them, of the species *Monopsyllus a. asio* (Baker).

The average measurements of 10 adults (4 males, 6 females) are: total length 175 (168-195); tail 46 (39-59); hind foot 19 (19-20); ear 16 (14-17); weight 64 (53-76).

On August 13, 1953, we anchored for the night off a small island about two acres in size. The position of the island, as best we could determine, was 53°57′N, 79°25′W. It was typical of the many small islands off the coast of northeastern James Bay, being low, not over fifteen feet high, and rounded. The island was obviously washed over by water during bad storms. There were large drift logs at the highest point. Here and there in the hollows on the island, a mossy sod had developed that supported a few species of higher plants including *Matricaria, Potentilla, Agrostis* and *Carex*. Wherever a patch of sod adjoined a pool of water, well used runs were found. Three nests were located, two barely concealed by the grass and one underneath a log. The nests were large and globular, about ten inches in diameter, and made of relatively coarse material outside with a small inner nest of finer materials.

One nest contained four approximately two-week-old *Microtus*, another, three approximately three-week-old *Microtus*, and the third, five babies estimated to be only three or four days old. When the nests were opened the older young immediately ran off, going without exception to the pools of water which they swam across with facility. When I first landed I had set out five traps. These were retrieved less than one hour later and found to contain four *Microtus*, two of which were adult females carrying embryos, R3L2-2 mm and R3L2-5 mm.

These voles were no different in coloration from those caught further north, nor did the teeth differ. With the exception of a slightly more obvious infraorbital foramen in the front view, there is nothing particularly unusual about the skulls. The ear measurement, however, was strikingly different, being two or three millimeters smaller (12-13, instead of 15-17 millimeters) than that of the mice collected further north.

Ondatra zibethica (Linneus) MUSKRAT

A muskrat was seen swimming in a small creek late at night on the west side of Richmond Gulf in 1950.

Synaptomys borealis Richardson NORTHERN BOG LEMMING

This was the least abundant of the microtines observed and captured. Within particular habitats, such as the neighborhood of water holes in the tundra, they were to be seen at any time, scurrying about on the muddy banks and chasing one another through the grass. While an occasional bog lemming was captured in the spruce or birch thickets, most were taken in the open, very wet places. They paid no attention to the

FIGURE 2A. Lichen-covered talus at Spruce Canyon where *Phenacomys* were trapped. The lack of runways, even about the entrances to burrows and cavities under boulders, is typical of those areas where *Phenacomys* abounded.

FIGURE 2B. Hole under boulder in which *Phenacomys* was storing stems of *V. Vitis-ideae*. Arrow indicates pile of stems removed.

FIGURE 2C. A typical *Microtus* run across a wet meadow. The bottom of the run itself had been beaten down almost a full inch below the original soil level.

FIGURE 2D. A typical *Dicrostonyx* burrow and its associated run on one of the beach terraces at Golfcourse Cove.

bait, being caught instead when they ran across the trap. There were no marked signs such as scat piles or grass cuttings that could be associated with this mouse.

Only two of the bog lemmings showed any signs of active breeding. One male taken on Merry Island, August 23, had fully developed and descended testes 13 mm in length. A female from Golfcourse Cove, caught September 10, carried three large embryos, R1L2-25 mm. For the most part these mice appeared to be yearlings. There were apparently two litters in the summer of 1953, the first by the adults of the previous season and a second by these adults and some of their progeny late in the season.

A very few had fleas, in every case *Monopsyllus a. asio* (Baker).

Average measurements of 19 adult specimens (8 males, 11 females) are: total length 133 (120-152); tail 20 (17-23); hind foot 18.5 (17-20); weight 31 (23-42).

Dicrostonyx hudsonius (Pallas) LABRADOR VARYING LEMMING

It was most surprising that only seven varying lemmings were obtained by trapping. They were not common, and few were seen abroad. Several were observed traveling along runs through thickets of willow and birch at Little Whale River and one running across the tundra at Golfcourse Cove. All that were trapped were caught below the surface of the ground beneath spruce roots, in rock crevices, or in large cavities near the water holes on open areas.

Distinctive varying lemming burrows (Figure 2D) were relatively common on the terraces at Richmond Gulf and many were excavated to determine their structure, to obtain lemmings, and to examine the nests for fleas. Their burrows are quite simple as can be seen from the diagrams of Figure 3. The typical occupied burrow had a small pile of fresh dirt at the entrance. A short length of tunnel, eighteen to twenty inches, led downward to a round, somewhat flattened nest of fine grass. The nest was not obviously differentiated into an outer and inner portion. There was usually a scat pile beneath the nest. If the burrow was branched, the branch was seldom currently used for any purpose and partially filled with moldy scats. Most burrows continued behind the nest for considerable distances. If the burrow was occupied, the lemming was always found at the extreme end attempting to dig out of danger. However, even in easily excavated sandy soil they appeared to make little headway, which may explain the simplicity of their burrows. The burrows that we observed had entrances either at the base of a dwarf willow or birch or at the foot of the beach terraces. Lemming pathways typically ran from clump to clump of shrubs and along the foot of the terraces. Each lemming apparently maintained a two- or three-burrow system inasmuch as only one animal was ever found in any one series of burrows obviously connected by runs. It would appear that the relationship between the lemmings and the other microtines was much the same as that of the woodchuck and the rabbit in northeastern United States. Many burrows examined at Richmond Gulf appeared to have been originally constructed by a lemming, whatever the rodent species occupying them at the time.

Lemming scat piles did not have the appearance of *Microtus* or *Phenacomys* piles inasmuch as the individual scats more or less remained separate. Some scat piles easily exceeded a foot in diameter and a height of six or more inches.

All of the lemmings captured alive died within a day or two. They usually lapsed into a rigor similar to that seen in *Zapus* after they have been caught by the tail or the foot on a cold and/or wet night. While it may have been symptomatic of an approaching cyclic die-off, this does not seem likely inasmuch as we found no dead lemmings while we were in the area.

No evidence of breeding was observed.

Both lemmings and their nests were remarkably free of ectoparasites. Only a very few fleas, *Monopsyllus a. asio* (Baker), were found in the nests. The specimens from Three Islands Harbor carried a few *Monopsyllus quirini* (Rothschild) and *Malareus p. dissimilis* Jordan.

Average measurements of 8 adults (5 males, 3 females) are: total length 143 (135-152); tail 16 (15-17); hind foot 20 (18-21); weight 66 (55-85).

Peromyscus maniculatus (Wagner) WHITE-FOOTED MOUSE

Two immature specimens of white-footed mice were collected on Merry Island. These were the only specimens secured. Cameron

and Morris (1951) found this mouse to be the second most abundant in the Lake Mistassini and Lake Albanel area inland and to the south. It would seem that the white-footed mouse tends to avoid the forest-tundra community typical of the areas we visited.

Zapus hudsonius (Zimmerman) HUDSON BAY JUMPING MOUSE

Two specimens of the Hudson Bay jumping mouse were caught at Moose Factory, July 29, 1950, at the point where a field bordered spruce forest. An adult male

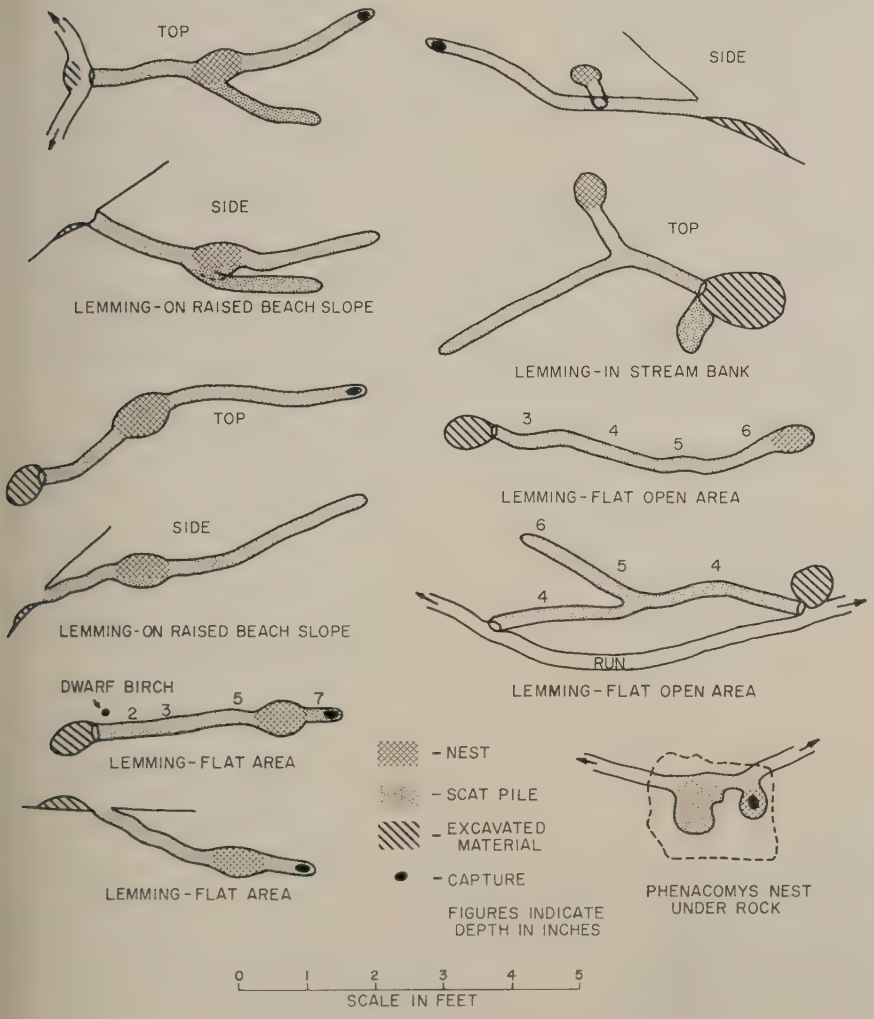

FIGURE 3. Burrows of varying lemmings and heather vole.

measured as follows: total length 205; tail 114; hind foot 32; weight 18.

Delphinapterus leucas (Pallas) BELUGA

The beluga was frequently observed from James Bay northward. This porpoise was not seen within Richmond Gulf. However, Chamberlin reports that one beluga closely circled the R/V *Lemming* while at anchor in southeastern James Bay, late in the summer of 1954.

REFERENCES

BANGS, O. 1897. On a small collection of mammals from Hamilton Inlet, Labrador. Proceedings of the Biological Society of Washington 11: 235-240.

CAMERON, A. W. AND WILLIAM A. MORRIS. 1951. The mammals of the Lake Mistassini and Lake Albanel regions, Quebec. National Museum of Canada Bulletin 123: 120-130.

DUTILLY, A. AND ERNEST LEPAGE. 1951. La Traversee de L'Ungava en 1945. Naturaliste Canadien 77: 136-181; 78: 5-77.

EDWARDS, R. L. AND J. LOCKWOOD CHAMBERLIN. 1951. Report on research grant. Yearbook of the American Philosophical Society 1950: 139-141.

———. 1962. Report on research grant. Yearbook of the American Philosophical Society 1961: 285-287.

FOSTER, J. BRISTOL. 1961. Life history of the *Phenacomys* vole. Journal of Mammalogy 42: 181-198.

HILDEBRAND, HENRY. 1959. Notes on an abundance of shrews (*Sorex cinereus cinereus*) and other small mammals in the Ungava Bay region of Far Northern Quebec. Journal of Mammalogy 30: 309-311.

HUSTICH, I. 1951. Forest-botanical notes from Knob Lake area in the interior of Labrador Peninsula. National Museum of Canada Bulletin 123: 166-217.

MARR, J. W. 1948. Ecology of the forest-tundra ecotone of the east coast of Hudson Bay. Ecological Monographs 18.

SMITH, DONALD A. AND J. BRISTOL FOSTER. 1957. Notes on the small mammals of Churchill, Manitoba. Journal of Mammalogy 38: 98-115.

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The relationship of cellular blood components to activity in certain marine teleosts. (Introduced by John M. Dean)

To determine if all cellular components of fish blood are related to the activity of the fish, the blood of eight species of marine teleost fishes was examined for the numbers of erythrocytes, thrombocytes, and leucocytes, and for mean cell volume, hematocrit value, and hemoglobin level. The fish used were the oyster toadfish, *Opsanus tau*; flounder, *Paralichthys* sp.; pinfish, *Lagodon rhomboides*; Atlantic croaker, *Micropogon undulatus*; false albacore, *Euthynnus alleterata*; bluefish, *Pomatomus saltatrix*; king mackerel, *Scomberomorus cavalla*; and Spanish mackerel, *Scomberomorus maculatus*. Blood samples were obtained from the kidney region with a hypodermic syringe. Techniques used in handling the blood were modified clinical procedures.

This investigation demonstrated that the active pelagic species, such as the mackerels, bluefish and albacore, have greater numbers of erythrocytes, higher hematocrit values, and greater amounts of hemoglobin than either the intermediate species, croaker and pinfish, or the benthic forms, toadfish and flounder. The leucocyte and thrombocyte numbers did not show any correlation with the activity of the fish.

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Progress in Oyster Mortality Studies

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INTRODUCTION

ERAL MASS MORTALITIES in oyster populations have occurred over the past
years and ineffectual attempts to control them have been made. A review
ome of these is given.

isease epidemics which virtually destroyed the entire oyster industry occur-
in Malpeque Bay, Prince Edward Island, Canada, in 1915, and over a
od of years spread to other areas within the Canadian Maritime Provinces
edler and Logie, 1947). The cause of this disease is still unknown, though
of several authors, cited by Laird (1961) suggests a different causative
nism. The oyster industry in the affected areas regained its former level
roduction by the 1930's, and it is hypothesized that the current populations
e are resistant strains that have developed from the survivors. Evidence
the infective agent is still present is suggested by the fact that introduced
ers are susceptible to the disease and die within the first or second year after
oduction (Needler and Logie, 1947). Research on several aspects of this
ase is continuing under the direction of Mr. Roy Drinnan at the Fisheries
earch Board Sub-Station in Ellerslie, Prince Edward Island, Canada (Drin-
, personal communication, 1962).

orringa's (1952) review paper on the biology of the oyster included a
mary of the European oyster epidemic. In 1919 mass mortalities of Euro-
n oysters (*Ostrea edulis*) occurred in Italy. In 1920 and 1921, a disastrous
er epidemic of a similar nature hit both the natural and artificial oyster
s in England, France, Germany, Denmark, and Holland. The theory has
n advanced that the disease was spread by oysters setting on the hulls of ships
taly and subsequently being transported with the disease agent to other
opean ports. Because there was no evidence of infection nor of parasites,
possibility of excessive rains and starvation were suggested as reasons for
mortalities. According to other investigators, however, this possibility is
cluded on the basis that identical ecological factors could hardly exist simul-
ously in such a diverse and vast area (Korringa, 1952).

n Holland during the 1930's and 1940's an outbreak of shell disease in
edulis was recorded. The agent responsible was classified as a fungus, and
sumably the infection was spread by spores carried in water currents. The
gus appeared to thrive on old decaying shells, particularly of *Cardium* and
pidula used as spat collectors. Removal of old shells and chemical treatment
pping) of planted oysters was suggested, and this treatment was used, up to
l at least, as a control measure for this disease (Korringa, 1951).

n the United States, an organism associated with oyster mortalities in the
lf of Mexico has been described. The parasite is a fungus and has been named
rmocystidium marinum (Mackin, Owen, Collier, 1950). This micro-organ-
has been fully implicated as the cause of heavy mortalities in oysters (Ray,
54), and can be positively diagnosed by culture techniques (Ray, 1952).

FIG. 1. Chart, showing locations mentioned in text

Andrews and Hewatt (1957) clearly established that *Dermocystidium* is
endemic to several areas in the lower Chesapeake Bay, and have worked
the intensity of infection and seasonal pattern of mortality caused by the
ganism in these areas. Further observations have revealed the presence of
fungus in oysters in Delaware Bay, in South Carolina (Andrews and Hew
1957), and in the middle portion of Chesapeake Bay (Dunnington, pers
communication, 1962). Mortalities caused by *Dermocystidium*, although oc
ring in some areas of the Gulf throughout the year, occur primarily in

mmer in more northerly latitudes when the water temperature and salinity relatively high.

The most devastating oyster mortality to have been reported in the United States is that which started in the spring of 1957 in Delaware Bay and continues to the present. The focal point of the disease was at first close to the New Jersey side of the Bay on the planted beds, but by the spring of 1958, oyster mortalities were reported along the Delaware shore (Fig. 1). By late summer of 1958, mortalities were reported in Rehoboth, Chincoteague, and Virginia seaside bays, though the heaviest mortalities were still reported from Delaware Bay. The first major mortality reported in Chesapeake Bay occurred in lower Virginia waters during the spring of 1959, and it was not until the summer of 1960 that mortalities due to this disease were confirmed in Maryland water in middle Chesapeake Bay (Fig. 1).

In 1957, under the guidance of Dr. Harold Haskin, biologists of Rutgers University conducting oyster research for the State of New Jersey began a study of the causes of mass oyster mortalities in Delaware Bay. Proximity and cross infection experiments under both natural and laboratory conditions, tray monitoring, and bacterial isolation were attempted to determine the extent and distribution of mortalities. A histological program was also begun in an attempt to discover if a histo-pathogenic agent was responsible for the mortalities. In 1958, a parasite thought to be the cause of oyster mortalities in Delaware Bay was discovered. This organism is a multinucleate sphere of unknown taxonomic position, hence it was tagged with the initials MSX (Haskin, personal communication, 1958. Fig. 7).

Since the time of its discovery in 1958, MSX has been observed in oysters in Chincoteague Bay, seaside Virginia, and in the lower part of the Chesapeake Bay in both Maryland and Virginia. Indeed, heavy mortalities believed to have resulted from infection by this parasite have prevented oyster plantings in some areas within the Virginia portion of the Chesapeake Bay (Andrews and Wood, 1961).

Another parasite, *Haplosporidium costale*, that possesses a definite spore stage, has been described in oysters from the Eastern Shore of Maryland and Virginia (Wood and Andrews, 1962). As this organism was found in oysters inhabiting the seaside regions, it has been called the seaside organism, or SSO, prior to its description in the literature.

Perspectives in the Study of Oyster Mortalities

The accomplishments in oyster mortality studies have come through the cooperative efforts of a great number of investigators currently involved in marine disease studies. Workshops and conferences among these researchers from state and federal agencies, universities, and industry are held at frequent intervals throughout each year. Ideas are exchanged, and progress, difficulties, and research plans are discussed in an uninhibited scientific atmosphere.

Despite these actions and accomplishments, progress in oyster mortality studies has been relatively slow principally because of the enormous complexities of the problems involved. A few examples of the problems that confront us are as follows:

1. *Mortalities caused by physical factors, predation, and competition.*

The continuing base levels of mortality that occur in the absence of specific disease must be determined and evaluated. Thus, during epidemic periods

mortalities due to factors other than disease can be distinguished from
due to disease.

2. *Absolute identification of the pathogenic organism suspected of cau*
disease.

The fungus *Dermocystidium* previously mentioned has some stages wi
its life cycle that are remarkably similar to some stages of MSX. Distribu
of *Haplosporidium costale* (SSO), like *Dermocystidium,* overlaps the distr
tion of MSX and to some extent produces overlapping peaks of morta
Haplosporidium also has certain stages that appear identical to certain st
of MSX to the inexperienced observer (Fig. 6).

3. *The life cycles and characteristics of the microparasites and other organi*
present in oyster tissues must be established.

The life cycle of the MSX parasite has not been completely described,
has its mode of transmission been established. Furthermore, the pictur
made even more complex by our relative lack of knowledge and life c
stages of such parasites as *Hexamita, Ancystrocoma, Bucephalus, Nematop*
bacteria, to name a few, that may cause mortalities when present in oy
tissues (Figs. 2-5).

4. *The question of resistance and susceptibility in oyster populations must*
answered and strain differences in the host and parasite must be studied.

It is possible empirically to develop resistant strains of oysters by breed
the survivors of mortalities experimentally, or by natural selection as occu
in Prince Edward Island (Needler and Logie, 1947) and to some exten
Delaware Bay (Haskin, Kunkle and Richards, 1961). However, in order
more fully understand the phenomena that occur, it is necessary to study
only the genetics and immune reactions of oysters themselves, but also
of the parasite responsible for mortality.

5. *The cytology, cytochemistry, and the metabolic processes of both the u*
fected and parasitized oyster must be more fully understood.

To devise specific and rapid diagnostic tests for diseased oysters and
interpret the results, it is essential to be able to recognize with certainty
various cell types before and after their exposure to various experime
staining procedures.

Furthermore, an understanding of the biochemistry of both healthy and
fected oyster tissues and fluids would assist investigators to develop ra
diagnostic and clinical tests for diseased oysters.

6. *A thorough understanding of the epidemiology of the oyster mortality*
disease pattern and an effective and efficient management program for
resource based on the accumulated information is essential.

Regulatory and conservation practices to prevent the spread of shell
disease and to institute control measures will be possible only through
understanding of disease patterns as they occur in a marine environment.

Research Activities by the Bureau of Commercial Fisheries in the Study of Shellfish Diseases

Research efforts prior to 1959 by the Bureau's Biological Laborat
presently located in Oxford, Maryland, were directed toward studies of
ecological (which included effects of predation and climate), conservat
and management aspects of oyster production. As the problem of morta
from disease became more severe, the research emphasis changed toward

expanded study of oyster mortalities as they occurred in the mid-central Atlantic states.

The Bureau's contributions in 1958 consisted of modest assistance through contracts to the biologists of Rutgers University who had already begun investigations of oyster mortalities in New Jersey. Later this support was increased and the contracts are continuing. The research being carried out at Rutgers includes the projects mentioned earlier plus an expanded effort, through detailed histological procedures, to discover the life cycle of MSX and to describe its various stages. In addition, they have begun a program of oyster larval culture designed to develop and test strains of oysters resistant to mortality.

In 1961 the State of New Jersey, with the cooperation of the oyster industry and the state shellfish research personnel, undertook a large scale experiment to test possible resistance of oyster seed to MSX. In the spring of this year, 10,000 bushels of seed oysters from the state seed beds were transplanted to parts of the private planted beds where MSX first struck five years before. These seed oysters were larger than normal but were the accumulated survivors of the sets of the previous five years. The larger of these oysters, harvested in the late fall of the same year, showed remarkable growth and survival.

The Congress of the United States recognized the need to assist oyster farmers in taking advantage of progress in the knowledge of disease resistance by passing HR 7336 which the President signed as Public Law 87-850. This law authorizes the purchase and transplanting of resistant oysters to aid in the rehabilitation of MSX damaged oyster areas.

The Bureau has also awarded contracts to marine biologists of the University of Delaware. The research at Delaware includes tray studies to aid in the determination of the extent and distribution of mortalities. They also include histochemical studies inaugurated to determine the significance of the presence of peculiar "brown bodies" in oysters and their role, if any, in combating disease.

The Bureau staff at Franklin City, Virginia, directed its attention to the mortality problem in 1959 and began tray studies for the purpose of determining the temporal distribution and intensity of mortalities.

In 1959 Bureau personnel, in cooperation with the Chesapeake Biological Laboratory and Maryland Department of Tidewater Fisheries, began a survey of the Maryland portion of Chesapeake Bay to determine the distribution and types of parasites in oysters. The results of this survey disclosed almost no pathogens in the oysters sampled. However, a few histological sections of oysters did reveal the presence of *Ancystrocoma* and *Nematopsis* (Burton, 1961).

The survey was expanded and continued in 1960, again with the cooperation of the Chesapeake Biological Laboratory and Maryland Department of Tidewater Fisheries. Results of this survey showed that although no mortalities were observed in the northern latitudes of Chesapeake Bay, they did occur and MSX was present in samples of oysters from Pocomoke Sound. Some *Dermocystidium, Hexamita, Bucephalus, Ancystrocoma,* and *Nematopsis* were also observed, primarily in oysters not infected with MSX (Burton, 1961).

A large number of specimens were collected and an almost overwhelming number of histological sections were prepared and examined during the surveys described above. Because of this, and because the information obtained from the surveys justified a change in sampling schedules, it was decided to limit our

program of sampling to three areas, but at frequent intervals, over the ent year of 1961. One of these (Pocomoke Sound) is located in an area wh mortalities have been observed, another area (Honga River) is located at edge of the mortality zone further up the Bay, and the third area is located w up the Bay in Broad Creek where no MSX has been observed. This program h been carried into 1962 also. Thus we have a sampling program which m disclose the spread of MSX, if it occurs, into the upper portions of Chesape Bay. We can also follow the distribution, intensity, seasonal pattern of m tality, and the degree of infection with MSX. Infected material can be u for our laboratory experiments. The results of our sampling program are yet incomplete, but it is anticipated that we will complete this one phase our data collection by the spring of 1963.

In addition to our survey, field sampling, and other field programs, we ha been conducting laboratory experiments over the past two years. The natu and results of each are outlined below:

1. A method that permits the identification of known parasites in oyster tiss within a few minutes after live oysters are brought into the laboratory is immense value. Such a method was developed for oyster tissue in our Oxfo laboratory, and employs the cryostat technique. It was adapted from that us for the rapid histological analysis of mammalian biopsy material. The succ of this technique has enabled us to begin other laboratory experiments w living parasites and with known infected oyster tissues (Carriker, 1962).

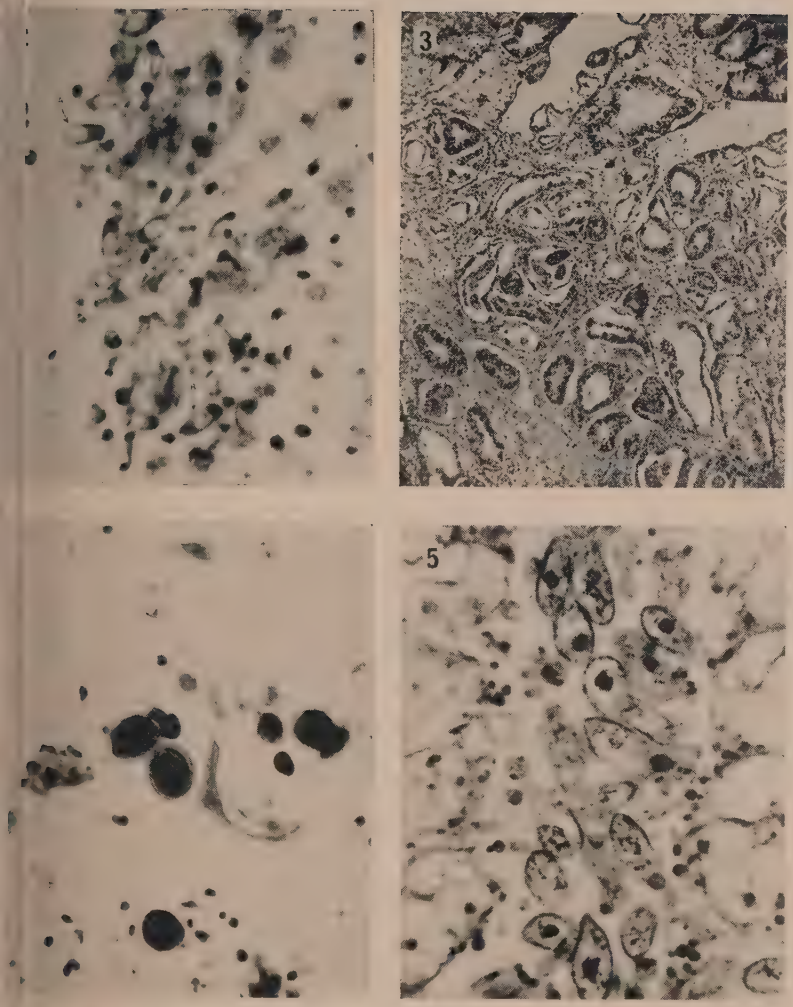
2. Cross infection experiments in attempts to determine the virulence of orga isms suspected of causing mortalities in oysters have been completed. In the experiments, oysters from epidemic areas (Delaware and Malpeque Bays) a presumably therefore carrying an infective agent, and oysters from areas nev having had a history of disease (Sheepscot River and Boothbay Harbor, Main were reciprocally crossed in recirculated seawater systems at various saliniti No mortalities due to disease were observed during the course of the expe ments, and preliminary histological examination indicated that Delaware B oysters when brought into the laboratory "lose" their infection under the expe mental conditions used. These results must still be regarded as preliminar However, they appear to agree with the results obtained in other laboratori in Delaware and Chesapeake Bays where cross infection experiments we employed.

A three-phased study, with the ultimate goal of distinguishing populations strain differences among oysters, was conducted in anticipation that resista genera or populations would be developed or found. In addition, these studi would add some basic knowledge to the field of oyster biology.

Chromosomal analyses of various oyster genera and species were starte Thus far, we have learned the chromosome numbers for *Crassostrea gig* and *O. edulis*, but further study of *C. virginica* material is needed (Rosenfie and Honey, unpublished data, 1962; Rosenfield and Lovejoy, unpublish data, 1962).

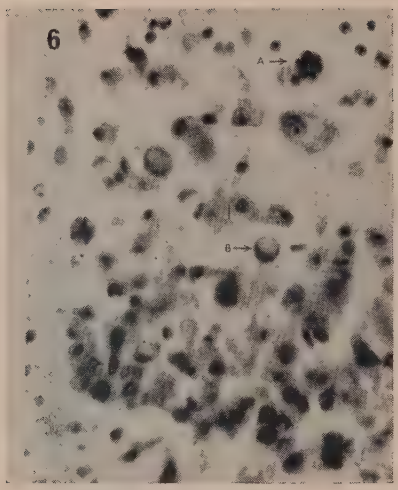
Starch gel electrophoresis studies of serum protein from various oyster pop lations have shown that this technique is a valuable tool to distinguish diffe ences in oysters on the generic level, but further refinements are necessa before it can be used for lower taxonomic levels.

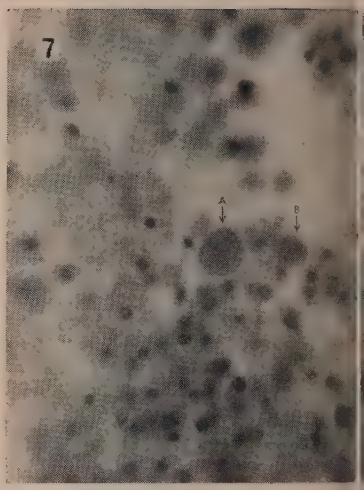
Rabbit antisera against sera from various groups of oysters have been d veloped, and serological differentiation tests are in progress.



ster Tissues: Sectioned at 6 microns; stained with iron haematoxylin and in. Various oyster parasites are shown. (Photographs taken by C. Austin ley, U.S.B.C.F., Oxford, Md.)

FIG. 2. *Hexamita* trophozoites (970X)
FIG. 3. *Bucephalus* cercariae in tubules of male gonad (430X)
FIG. 4. Nematopsis spores (970X)
FIG. 5. *Ancystrocoma* (970X)





Oyster tissues: Sectioned at 6 microns; stained with iron haematoxylin eosin. (Photographs taken by C. Austin Farley, U.S.B.C.F., Oxford, Md.

FIG. 6. *Dermocystidium* (970X) (a) Rosette stage (b) Hypnospore st
FIG. 7. MSX: Note Plasmodia at A and B.

ACKNOWLEDGEMENT

A host of people are interested in these very serious problems and thro the past four years their help, advice, and criticisms have had their benefi effect on the progress of the program. We could not name them all but m tion only a few like T. C. Nelson, L. A. Stauber, M. R. Carriker, J. H. I row, J. C. Mackin, J. B. Glude, C. J. Sindermann and our many colleague the state and university biological laboratories of New Jersey, Delaware, M land, Virginia, and Texas who are well aware of the problems and vicissitu involved in our common undertaking.

REFERENCES

ANDREWS, J. D. AND W. G. HEWATT
1957. Oyster mortality studies in Virginia II. The fungus disease caused *Dermocystidium marinum* in oysters of Chesapeake Bay. Ecol. Mo graphs 27: 1-26.

———AND J. L. WOOD
1961. Status of diseases of oysters in Chesapeake Bay. Virginia Institute Marine Science Special Report No. 1: 1-5.

BURTON, R. W.
1961. Distribution and observations of oyster microparasites in Maryl Chesapeake Bay. Proc. Nat. Shellfisheries Assoc. 1961: (In press)

CARRIKER, M. R.
1962. Preparation of frozen sections of oysters for pathological studies some applications of the method. Proc. Nat. Shellfisheries As 1961: (In press).

HASKIN, H. H., D. KUNKLE AND W. A. RICHARDS
1961. Recent developments in Delaware Bay oyster mortalities. Proc. Nat. Shellfisheries Assoc. 1961: 8 (Abstract).

HERRINGA, P.
1951. Investigations on shell-disease in the oyster *Ostrea edulis* L. Conseil Permanent International Pour L'Exploration De La Mer 128: 50-54.

1952. Recent advances in oyster biology. Quart. Rev. Biol. 27: 266-308; 339-365.

HIRD, M.
1961. Microbiological factors in oyster epizootics. Can. J. Zool. 39: 449-485.

MACKIN, J. G., H. M. OWEN AND A. COLLIER
1950. Preliminary note on the occurrence of a new protistan parasite, *Dermocystidium marinum* n.sp. in *Crassostrea virginica* (Gmelin). Science 111: 328-329.

MEDLER, A. W. H. AND R. R. LOGIE
1947. Serious mortalities in Prince Edward Island oysters caused by a contagious disease. Trans. Royal Soc. Canada *41* (3): 73-89.

RAY, S. M.
1952. A culture technique for the diagnosis of infection with *Dermocystidium marinum* Mackin, Owen and Collier in oysters. Science 116: 360-361.

1954. Experimental studies on the transmission and pathogenicity of *Dermocystidium marinum*, a fungus parasite of oysters. Jour. Parasitol. 40: 235.

WOOD, J. L. AND J. D. ANDREWS
1962. *Haplosporidium costale* (Sporozoa) associated with a disease of Virginia oysters. Science 136: 710-711.

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TABLE 1. THE MEAN LENGTHS (MILLIMETERS) OF LIVE FISH AND FISH PRESERVED FOR INCREASING LENGTHS OF TIME, GROUPED BY LENGTH CLASSES

Length Classes	Live Length l	(Preserved 30 min) f_1	(Preserved 1 Week) f_2	(Preserved 2 Weeks) f_3	(Preserved 6 Weeks) f_4	Percentage of Live Length After 6 Weeks	N
3.05–3.5	3.45	3.24	3.22	3.19	3.17	91.7	6
3.55–4.0	3.79	3.48	3.40	3.38	3.36	88.8	13
4.05–4.5	4.33	3.94	3.88	3.86	3.84	88.7	12
4.55–5.0	4.86	4.59	4.46	4.42	4.40	90.4	18
5.05–5.5	5.37	5.17	5.03	5.02	5.00	93.2	7
5.55–6.0	5.87	5.54	5.47	5.45	5.46	93.0	15
6.05–6.25	6.19	5.75	5.67	5.63	5.59	90.3	4

SHRINKAGE OF SARDINE (*SARDINOPS CAERULEA*) LARVAE UPON PRESERVATION IN BUFFERED FORMALIN. — A description of the effects of formalin preservation on the length of yolk sac sardine larvae may prove useful in determining the live lengths of preserved sardine larvae.

Sardine eggs taken from the sea with a plankton net at San Diego, California, were sorted by stage of development into quart jars of fresh sea water. About 10 eggs per jar were incubated at $14.0 \pm 2°C$.

Random samples of live larvae were measured individually with an ocular micrometer. The individual larvae, placed in numbered vials, were killed with borax-buffered, three per cent formalin.

The larvae were measured again at the end of 30 minutes, 1 week, 2 weeks, and 6 weeks, and recorded as f_1, f_2, f_3, and f_4. Table 1 shows mean live lengths grouped by 0.5 mm size classes and the mean preserved lengths at each measuring period. Average live length for each size class was plotted against the average length by size class for the preserved larvae for each of the measuring periods. These plots were slightly concave. (See also percentage of live length after 6 weeks, Table 1.) Using the individual observations ($N = 75$) the linear regression, formalin length on live length, was computed: formalin length (f) $= a + b$ live length (l). In addition, the regression live length on log preserved length was computed and the variances compared by an f test. The reduction in variance brought about by the log transformation was not significant. The statistics for each of the four regressions are given in Table 2.

Measurements were made without reference to previous measurements, but were recorded so that the individual history of each fish could be followed. Fifteen of 375 measurements yielded lengths greater than the preceding measurements. This may represent measuring errors. Assuming random measuring error, 15 cases should be shorter than the actual measurement. The error of measurement may then be about eight per cent (30 of 375).

The standard deviations of the slopes (s_b) are given in Table 2 and do not indicate significant departures from a slope of 1.0 ($f_1 : t = 0.477$, $f_2 : t = 1.54$, $f_3 : t = 1.58$, $f_4 : t = 1.38$). However, the standard deviations of the intercept (s_a) do indicate sig-

TABLE 2. REGRESSION STATISTICS FOR THE RELATIONSHIPS BETWEEN THE LENGTHS OF LIVE SARDINE LARVAE AND THEIR LENGTHS AFTER PRESERVATION IN FORMALIN

	Intercept a	Slope b	Mean Live Length $\bar{l}$	Mean Preserved Length $\bar{f}_*$	Variance of the Regression s^2_{l/f_*}	Standard Deviation of Slope s_b	Standard Deviation of Intercept s_a
f_1 (30 minutes)	–0.26*	0.9863	4.80	4.49	0.0344	0.0249	0.1212
f_2 (1 week)	–0.25*	0.9664	4.80	4.40	0.0264	0.0218	0.1138
f_3 (2 weeks)	–0.27**	0.9662	4.80	4.38	0.0255	0.0214	0.1047
f_4 (6 weeks)	–0.29**	0.9724	4.80	4.36	0.0221	0.0199	0.1012

a tested for difference from zero * = 5% ** = 1%.
b tested for difference from 1.0. None is significant at the 5% level.

nificant departures from zero ($f_1 : t = 2.15$, $f_2 : t = 2.19$, $f_3 : t = 2.58$, $f_4 : t = 2.87$). Furthermore, the greatest amount of shrinkage took place in the first 30 minutes and constitutes an actual decrease in length of about 0.25 mm. The linear regressions with slopes of 1.0 and intercepts of about –0.25 suggest that sardine larvae shrink about 0.25 mm when exposed to borax-buffered, three per cent formalin. Therefore, live and preserved lengths can be made comparable by adding this increment to the length of preserved specimens.—David A. Farris, *Dept. of Zoology, San Diego State College, San Diego, California.*

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Reproductive Periodicity in the Sardine (*Sardinops caerulea*) and the Jack Mackerel (*Trachurus symmetricus*) on the Pacific Coast of North America

David A. Farris

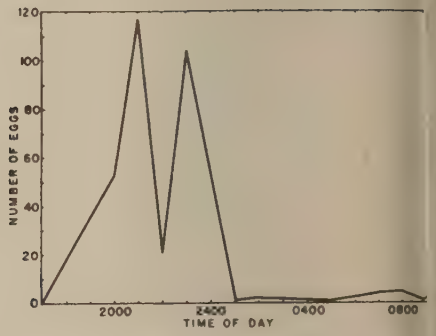

Fig. 1. Freshly spawned sardine eggs by ho of collection.

REPRODUCTIVE PERIODICITY IN THE SARDINE (*SARDINOPS CAERULEA*) AND THE JACK MACKEREL (*TRACHURUS SYMMETRICUS*) ON THE PACIFIC COAST OF NORTH AMERICA. —Reproductive periodicity in Pacific sardines and jack mackerels was investigated because of the general interest in reproductive rhythms (Brown, 1959, *Science 130:1535–44*). The estimation of the abundance of pelagic marine fish eggs is partially dependent on a known and regular temporal distribution. If such a distribution is not evidenced, the linear interpolation of egg numbers in tir will be biased (Sette and Ahlstrom, 194 *Sears Found. J. Mar. Res. 7[3]:511–42* If these fishes spawn on a lunar cycle, tl search for eggs for laboratory studies cou be limited to certain periods.

Since 1949, a regular grid of oceanograph collecting stations has been occupied l the Bureau of Commercial Fisheries Biolo ical Laboratory at La Jolla, California, monthly intervals. All eggs, having bee separated from the plankton samples, a sorted to species and counted. These coun are made comparable for variations i amounts of water strained by the samplir net by the standardization procedure give by Ahlstrom (1952, *U. S. Dept. Int. Fish an Wildlife Service, Spec. Sci. Rept., Fisheri No. 80*).

TABLE 1. STANDARD NUMBERS OF SARDINE EGGS, NUMBERS OF PLANKTON HAULS, AND CATCH PER HAUL BY LUNAR WEEK (MARCH–JUNE 1950–56)

Year	Lunar Week I			II			III			IV		
	Standardized Number of Eggs	Number of Plankton Hauls	Average Catch Per Haul	Standardized Number of Eggs	Number of Plankton Hauls	Average Catch Per Haul	Standardized Number of Eggs	Number of Plankton Hauls	Average Catch Per Haul	Standardized Number of Eggs	Number of Plankton Hauls	Average Catch
1950	34,182	180	189.9	11,195	215	52.1	490	52	9.4	177	24	7.4
1951	360	7	51.4	2,895	103	28.1	38,796	291	133.2	60,598	146	415.0
1952	17,866	289	61.8	10,148	172	59.0	5,966	75	79.5	3,153	154	20.0
1953	1,940	92	21.1	5,792	321	33.7	12,638	322	168.5	208	56	1.4
1954	28,230	159	177.5	7,369	27	272.9	12,057	190	63.4	22,887	384	59.6
1955	5,669	176	32.2	8,893	204	43.6	9,309	157	59.3	4,546	103	44.1
1956	2,182	59	37.0	7,112	220	32.3	32,115	326	98.5	17,173	165	104.1
Total	90,429	962	——	53,404	1,262	——	111,371	1,413	——	108,742	1,032	——

ABLE 2. STANDARD NUMBERS OF JACK MACKEREL EGGS, NUMBERS OF PLANKTON HAULS, AND CATCH PER HAUL BY LUNAR WEEK (MARCH–JUNE 1950–56)

	Lunar Week											
	I			II			III			IV		
ear	Standardized Number of Eggs	Number of Plankton Hauls	Average Catch Per Haul	Standardized Number of Eggs	Number of Plankton Hauls	Average Catch Per Haul	Standardized Number of Eggs	Number of Plankton Hauls	Average Catch Per Haul	Standardized Number of Eggs	Number of Plankton Hauls	Average Catch Per Haul
51	3,887	7	555	9,925	103	96	77,517	291	266	46,198	146	316
52	65,642	289	227	14,278	112	83	18,721	75	250	32,512	154	211
53	0	92	0	38,742	321	121	115,625	322	359	24,911	56	445
54	30,570	159	192	4,579	27	170	708	190	4	79,508	384	207
otal	100,099	547	–	67,524	623	–	212,671	778	–	183,129	740	–

Ahlstrom (1952, *op. cit.*) (1953, *Ibid., No. 02*) (1954, *Ibid., No. 123*) (1958, *Ibid., No. 51*) and Ahlstrom and Kramer (1955, *U. S. ept. Int. Fish and Wildlife Service, Spec. i. Rept., Fisheries No. 155*) (1956, *Ibid., o. 186*) (1957, *Ibid., No. 224*) listed andard counts of sardine eggs, and the andard counts of jack mackerel eggs were ven by Farris (1958, *U. S. Dept. Int. Fish nd Wildlife Service, Spec. Sci. Rept., Fish- ies No. 263*). In addition, the date each lankton sample was taken is given by staff f the South Pacific Fisheries Investigations (now the Biological Laboratory at La Jolla) (1952, *U. S. Dept. Int. Fish and Wildlife Service, Spec. Sci. Rept., Fisheries No. 73*) (1953, *Ibid., No. 100*) (1954a, *Ibid., No. 125*) (1954b, *Ibid., No. 132*) (1955, *Ibid., No. 161*) (1956, *Ibid., No. 177*) and Thrail-kill (1957, *U. S. Dept. Int. Fish and Wildlife Service, Spec. Sci. Rept., Fisheries No. 232*). The dates each station was occupied (i.e., plankton hauls taken) were assigned to lunar weeks (the dark of the moon falls between lunar weeks two and three). Since most spawning by the sardine and jack mackerel

ABLE 3. ABUNDANCE OF SARDINE EGGS (IN BILLIONS) BY MONTH OFF CALIFORNIA (N) AND BAJA CALIFORNIA (S) 1950–56

		J	F	M	A	M	J	J	A	S	O	N	D
950	N	–[1]	0	0	804	6,958	27,102[2]	149	16	0	–	–	–
	S	–	10,488	36,916	149,314	46,062	1,643	5,802	0	423	–	–	–
951	N	0	0	211	202	10,927	4,065	315	0	0	0	0	0
	S	11,436	69,598	265,066	65,166	90,008	31,993	30,210	9,663	353	30,736	6,932	1,971
952	N	3	0	139	496	1,521	74	422	8	0	0	0	0
	S	2,422	7,132	27,745	22,609	18,704	19,227	2,122	14,450	10,189	536	20	–
953	N	0	20	0	2	36	24	593	0	0	0	0	0
	S	136	41,066	12,874	16,455	12,051	3,749	189,099	151,667	7,728	1,474	0	1,682
954	N	0	19	2	5,286	12,412	17,747	11,728	0	–	0	–	0
	S	41,468	50,493	43,723	40,757	37,568	28,323	57,824	7,435	–	0	–	573
955	N	0	0	1,761	342	7,184	8,679	96	–	0	0	–	0
	S	21,333	18,557	13,197	40,012	28,486	7,495	10,574	–	–	2,274	–	2,652
956	N	0	0	77	16	18,546	10,154	374	–	–	83	0	0
	S	2,674	13,563	17,755	24,420	13,281	54,159	70,794	23,583	6,520	0	0	0

[1] A dash (–) indicates no cruise made.
[2] Underlined numbers indicate the peak month of spawning.

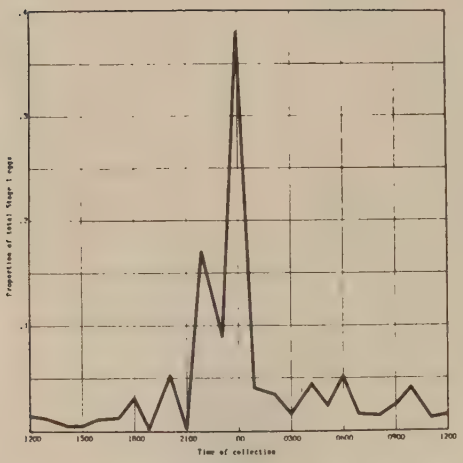

Fig. 2. Freshly spawned jack mackerel eggs by hour of collection.

takes place between the first of March and the end of June, only the data for those four months were examined. The numbers of eggs by lunar week (Table 1) were totaled for the four months for each year, and were divided by the total number of hauls made during that lunar week to give the average number of eggs per haul per lunar week for each year.

McEwen (1949, *Proc. of the Berkeley Symposium on Mathematical Statistics and Probability, Univ. of Calif. Press, pp. 229–38*) showed that true periodicity may be distinguished by a greater variance within cycles than between them. The between-lunar-week variance of the catch per haul of sardine eggs was computed (446) and compared with the residual variance (9,233) by an *F* test. The catch per haul of sardine eggs does not show lunar periodicity. The between-lunar-week variance of catch per haul of jack mackerel eggs (Table 2) wa 22,136 with the residual variance of 18,027 also indicating no lunar periodicity in th catch per haul.

Ahlstrom (1950, *U. S. Dept. Int. Fish an Wildlife Service, Spec. Sci. Rept., Fisherie No. 15, pp. 135–7*) indicated a diurnal pe riodicity in sardine spawning with maximun from 8 to 12 PM, by using the abundanc of precleavage sardine eggs by hour of co lection (Fig. 1) to illustrate this observation

Farris (1961, *U. S. Dept. Int. Fish an Wildlife Service, Fisheries Bulletin No. 18 61:250*) indicated a spawning preference a about midnight and a diurnal rhythm i jack mackerel spawning (Fig. 2).

A seasonal preference in sardine spawnin is suggested in Table 3. Ahlstrom suggeste at least two subpopulations of sardines (1958 *California Cooperative Oceanic Fisheries In vestigations Report 7:173–9*; Estimates o total sardine egg abundance) (Ahlstrom 1954, *U. S. Dept. Int. Fish and Wildlif Service, Fishery Bulletin 93 56:83–140* an 1959, *Ibid., 165 60:185–213*) were divide into northern and southern groups. Th northern sardines exhibit a spawning peak within the May–July period while that fo the southern sardines is more erratic (Table 3).

The estimates of total abundance of jack mackerel eggs by month are listed in Table 4 indicating that the peak of spawning ac tivity falls from March to May. There are no indications of subpopulations in jack mackerel and the data are not subdivided From these observations it may be con cluded that Pacific sardines and jack mack erel exhibit diurnal and seasonal periodicity but do not exhibit lunar periodicity.—DAVID A. FARRIS, *San Diego State College, San Diego, California.*

TABLE 4. ABUNDANCE OF JACK MACKEREL EGGS (IN BILLIONS) BY MONTH OFF THE PACIFIC COAST OF NORTH AMERICA 1951–54

	J	F	M	A	M	J	J	A	S	O	N	D
1951	0	64,200	272,200[1]	171,900	128,010	151,500	68,000	17,100	+[2]	0	0	0
1952	2,000	50,500	75,800	119,000	175,800	95,100	61,600	9,000	4,100	0	0	–[3]
1953	0	37,800	105,300	178,300	214,500	124,500	67,600	7,900	0	200	0	0
1954	300	24,300	56,400	123,600	136,100	73,800	44,400	3,400	–	+	–	0

[1] Underlined numbers indicate the peak month of spawning.
[2] Plus (+) indicates less than 100 eggs taken.
[3] Dash (–) indicates no cruise made.

OCEANOGRAPHIC CONDITIONS AND SALMON DISTRIBUTION SOUTH OF THE ALASKA PENINSULA AND ALEUTIAN ISLANDS, 1956

by
Felix Favorite, Oceanographer
and
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ABSTRACT

[illegible] and related oceanographic cruises in the North [illegible] in 1956 are summarized, and comparison is made [illegible] salmon catches and oceanographic features determined [illegible] collected aboard the chartered fishing vessels *Mitkof*, [illegible] Oregon in the area south of the Alaska Peninsula and [illegible] Islands in the summer of 1956.

[illegible] relationship between surface conditions and the [illegible] abundance of salmon in the eastern Pacific is indicated. [illegible] surface temperature front at approximately lat. 48°N. [illegible] with the southern limit of summer catches. In the [illegible] salmon were caught by the vessels of the [illegible] Agency and a Bureau of Commercial Fisheries [illegible] as far south as lat. 41°N.–42°N.

[illegible] oceanographic information was obtained in 1956, [illegible] by various agencies in 1958 are utilized to show the [illegible] proximity of two oceanographic fronts in the area con[illegible]. A salinity front at lat. 42°N. coincides with the southern [illegible] catches, and a temperature front at approximately [illegible] in the eastern Pacific, extending to lat. 46°N. in the [illegible] Pacific, coincides with the southern limit of summer [illegible].

[illegible] very little is known concerning the high-seas migra[illegible] salmon, it appears that northward of approximately lat. [illegible] in the eastern Pacific and lat. 46°N. in the western Pacific, [illegible] surface layer north of the temperature frontal zone [illegible] salmon to remain near the surface, where they would [illegible] vulnerable to capture in surface nets during the summer. [illegible] investigations indicate that they are not present at depths [illegible] seldom during this period.

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INTRODUCTION

Prior to the development of the Japanese commercial high-seas salmon fishing in the North Pacific Ocean in 1952, very little was known about the marine habitat of the Pacific salmons (genus *Oncorhynchus*). Since 1955, the United States Bureau of Commercial Fisheries, serving as a research agency of the International North Pacific Fisheries Commission (INPFC), has been engaged in a study to determine the extent of intermingling of Asian and North American salmons in the North Pacific Ocean and the Bering Sea. One phase of this study is to determine the extent of oceanic salmon environment and the oceanographic conditions affecting their distribution and movements. Therefore, the purpose of this report is threefold:

1. To summarize various oceanic salmon fishing and related oceanographic cruises prior to 1956 that provide information on the distribution of salmon and the oceanic environment.

2. To present results of the fishing and oceanographic programs, carried out aboard chartered fishing vessels *Mitkof*, *Celtic* and *Paragon* southward of the Alaska Peninsula and Aleutian Islands in 1956, which show the southern limit of the salmon distribution in that summer.

3. To compare results of the above cruises and those conducted by the Japan Fisheries Agency in the spring of 1956, with oceanographic features that may determine the southern extent of salmon distribution in spring and in summer.

REVIEW OF SALMON FISHING AND OCEANOGRAPHIC CRUISES PRIOR TO 1956

An excellent review of the history of the Pacific salmon is presented in Bulletin No. 1 of the International North Pacific Fisheries Commission (INPFC, 1955). The following is a brief summary of studies on the marine environment of the salmon near the Aleutian Islands.

Investigations Prior to 1952

Taguchi (1956) reported that for more than 10 years prior to 1941 the Japanese had fished for salmon off the east and west coasts of Kamchatka, U.S.S.R., and were aware that the salmon fed and matured in an unknown area in the North Pacific Ocean. They believed that the ocean currents controlled the migration routes of the salmon.

The results of coastal tagging experiments prior to 1952, summarized by Hartt (1959), indicated a wide range of salmon migrations across the North Pacific, but did not reveal the extent of the oceanic distribution of the salmon. Early oceanographic cruises, excluding those by the Japanese, provide only fragmentary environmental data in the North Pacific, and have been summarized by Fleming (1955). Data from Japanese cruises have been compiled by the Japan Agricultural Technical Association (1954).

The U.S. Bureau of Fisheries made the first investigation to obtain oceanographic observations in conjunction with a salmon fishing effort near the Aleutian Islands and in the Bering Sea during the spring and summer of 1939, 1940 and 1941. World War II interrupted this investigation before it was completed, and no specific relationships between the salmon and environmental factors were determined. Ba (1952) reported the results of the fishing cruise the oceanographic data have been recovered an sented by Favorite and Pedersen (1959a) and Fa *et al.* (1961). The area is essentially a coastal en ment, and the study was concerned directly wi salmon runs into Bristol Bay streams.

Investigations During 1952 to 1954

The Japanese commercial high-seas salmon f fleets which commenced gillnet operations i western North Pacific Ocean and Bering Sea in proved that good catches of salmon could be ma the high seas. Data from these commercial c tions are difficult to obtain, but reports by Tagucl Hirose (1954), Taguchi (1955) and Taguchi Shoji (1955) have shown relationships between sa migrations and movements of water masses, parti ly in the area south and west of the western Alet Islands. It was noted, however, that in some tions the direction and velocity of the currents quite variable. Taguchi (1957) reported tha dichothermal water (layer of cold water at depth occurs as a temperature minimum) showed the of the Oyashio Current, and also that the sou boundary of salmon catches occurred along th where the Kuroshio Current converges with the shio.

The oceanographic cruises of the *Tenyo-maru* (Regional Fisheries Research Laboratory), durin period of operation of the Japanese high-seas sa fleet in the summer of 1952 and 1953, were so the first investigations directed toward an u standing of the oceanic environment of the sal Watanabe (1954), utilizing these and other hist oceanographic data, summarized the general oc graphic conditions in the North Pacific. He rep that the major fishing grounds were at the bou of the cold, northern surface water and the warm of southern origin, and that better salmon catches made in areas of sharp horizontal temperature salinity gradients associated with upwelling. and Honjo (1954), reporting on the biologica servations of the *Tenyo-maru* cruise in the sum 1952, noted that good salmon catches were asso with plankton concentrations found in the west flowing current south of the Aleutian Islands.

In 1953, the *John N. Cobb* (U.S. Fish and W Service) made an exploratory fishing cruise alon Aleutian Islands, but only surface observations made (Schaefers and Fukuhara, 1954).

The *Oshoro-maru* (Faculty of Fisheries, Hok

ersity), during student training cruises in the ian area in the summer of 1953 and 1954, made ined oceanographic and exploratory salmon g studies. The results of the oceanographic s, presented by Mishima and Nishizawa (1955), bed the water structure in the western Aleutian and showed that the area was characterized by per layer of cold, low salinity water and a lower of warm, saline water. They also noted that a , low salinity water mass flowed westward on the ern side of the Aleutian Islands, extending as est as 165° East longitude.

STIGATIONS BY THE INTERNATIONAL NORTH PACIFIC RIES COMMISSION, 1955

e present marine investigations by the member ns of INPFC, Canada, Japan, and the United s, commenced in the summer of 1955. The *Tsu-a-maru* (Japan Fisheries Agency) made a salmon g cruise in the Bering Sea and south of the tian Islands, where limited oceanographic ob-tions were made. During the same period the au of Commercial Fisheries used the *John N. Cobb* the chartered fishing vessels *Mitkof* and *Paragon* ake combined oceanographic and fishing cruises e Gulf of Alaska and south of the Aleutian Islands. esults of the experimental fishing have been reported by Powell and Peterson (1957). The limited oceanographic data (Favorite and Love, 1957) collected aboard the fishing vessels were inadequate to describe the oceanographic features in the area, but fortunately the fishing operation coincided with the international oceanographic program NORPAC, which provided an oceanographic survey of the North Pacific Ocean. The results of the oceanographic observations should appear shortly in atlas form.

The 1955 fishing operation directed by the American Section of the INPFC showed it was possible to catch salmon in gillnets in the eastern part of the North Pacific Ocean north of approximately lat. 47°N. An extensive experimental fishing and oceanographic program was planned by the American Section for the 1956 season.

OCEANOGRAPHIC CONDITIONS AND SALMON CATCHES, SUMMER 1956, (MV *MITKOF*, MV *CELTIC* AND MV *PARAGON*)

Except for the rather gross effects of temperatures outside the lethal limits, we know little about the oceanographic properties or features which may affect the distribution of salmons. Often an investigator will select one property such as temperature or salinity

FIGURE 1. Locations of fishing sets and distribution of salmon, steelhead and albacore during the period May to September, 1956, as determined by the catches of the vessels *Mitkof*, *Tordenskjold*, *Paragon*, *Celtic* and *John N. Cobb*. Numbers indicate serial order of sets (from Hanavan and Tanonaka, 1959).

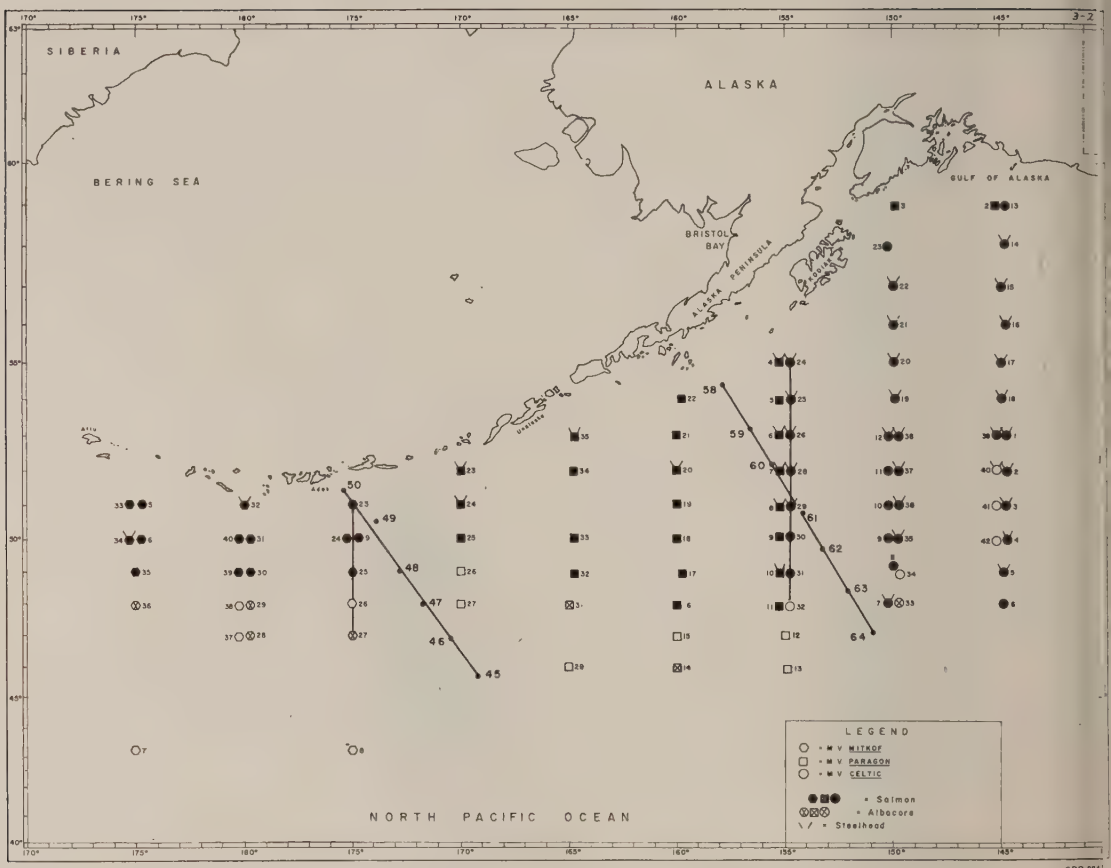


FIGURE 2. Oceanographic stations south of the Alaska Peninsula and Aleutian Islands, Summer 1956. The solid lin indicate locations of vertical sections described in the report. (*New Glasgow* stations 45 to 50 and 58 to 64 are indicate by small dots.)

and relate it to a biological phenomenon, but this tells only a small part of the story and may not hold true in another area or under different circumstances. Until we know more of the reaction of salmon to changes or extremes of temperature and salinity, we must consider the environment as a whole. For this reason, the oceanographic data obtained aboard the charter vessels have been treated in several different ways to show as specifically as possible different environments, that is, different water structures, that might be detected by the salmon. At this stage of our investigation perhaps some of these differences may appear unimportant, but they have been sought out and presented because they may prove valuable in planning future research.

Sources of Data

The locations at which fishing sets were made in the summer of 1956 by the *John N. Cobb* and four chartered fishing vessels *Mitkof*, *Paragon*, *Celtic* and *Tordenskjold*, as presented by Havanan and Tano (1959), are shown in Figure 1.

The *Cobb* made 27 fishing sets on and eastwa long. 145°W., resulting in a total catch of onl salmon. These sets, as well as those of the *Mitkof* and *Paragon* eastward of long. 145°W. w no or only a few salmon were caught, are not sidered in this report. Also excluded are the *M* and *Tordenskjold* Bering Sea sets, which will be discu in a separate report.

The *Mitkof*, *Paragon* and *Celtic* stations provi comparison of oceanographic conditions and sal catches south of the Alaska Peninsula and the Ale Islands (Fig. 2).

Personnel of the Department of Oceanogra University of Washington, Seattle, Washington, u the direction of Dr. Richard H. Fleming, carrie the oceanographic program aboard the charter ve Love (1957, 1959) has described the oceanogra

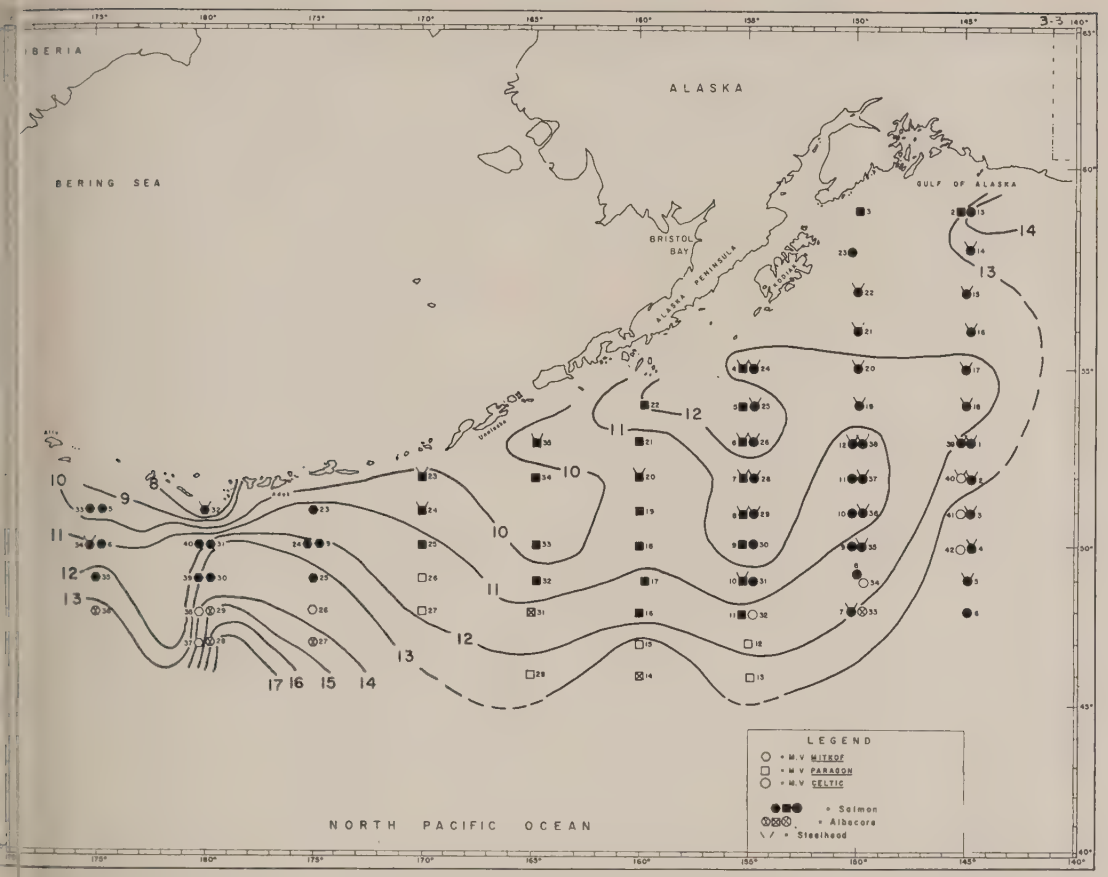


FIGURE 3. Surface temperature (°C.), Summer 1956, showing the absence of any sharp gradients except at 180°.

cdures used aboard the vessels and has tabulated ysical and chemical data. To augment the serations of horizontal and vertical sections of teproperties constructed from these data, addition- nrmation from the 1956 summer cruise of the *New Glasgow* (Pacific Oceanographic Group, 7) have been utilized. The locations of these ics are shown also in Figure 2.

ould be noted that the presence or absence of has been determined from surface gillnet ch, and that by August the majority of the tung salmon have left the oceanic environment e approaching or have entered the streams to w The results of the Canadian exploratory is eastward of the area discussed in this report ve een published (Manzer, 1958).

E Conditions in Relation to Salmon Dis- ION

on have often been considered predominantly ce fish; thus, relationships between oceano- graphic conditions and salmon distribution were sought in the surface layer. One might assume from the locations of salmon catches shown in Figure 1 that the absence of salmon in gillnet catches south of lat. 48°N. would be associated with sharp gradients of surface water properties indicating the presence of another water mass with different physical and chemical properties that could be detected by salmon. This is not indicated by our data which show a gradual transition in surface water properties in contrast to an abrupt change in properties at greater depth.

In order to present as complete a picture as possible of the surface conditions, *Oshoro-maru* (Hokkaido University, 1957) and *New Glasgow* data have been used in contouring the surface temperature and salinity distributions. The locations of these stations are not shown because fishing sets were not made.

Surface temperature. The July-August surface temperatures have been combined to show the summer temperature distribution in the fishing area (Fig. 3). Sharp gradients occur only at long. 180° where the

intrusion of warm water (13°C. to 17°C.) from the south is apparent. South of lat. 50°N. between long. 145°W. and 175°W., the surface temperature gradient is approximately 1°C. per 60 miles. This does not appear to constitute an effective environmental boundary for the southern distribution of salmon, particularly in view of the fact that at *Mitkof* station 25 salmon were caught in surface temperatures greater than 13.5°C. Using this temperature as an upper threshold, salmon should have been caught as far south as lat. 45°N. between long. 145°W. and 165°W.

Figure 1 also reveals a slight northward shift in the southern limit of catches along long. 145°W., 150°W. and 155°W. as the season progressed (as indicated by the higher set numbers). This apparent northward movement of the salmon was not accompanied by an appreciable change in the surface temperature except at long. 145°W. where the divergence of the Subarctic Current greatly complicates the circulation off the North American coast. Tables 1 and 2 compare salmon catches and surface conditions at repeated sets on long. 150°W 155°W. A rise of only 1°C., generally from to 11°C., was associated with no catches of in August at stations where salmon had been in July. Since salmon were caught at 16 other sets where temperatures were greater than 12°, cannot say that surface temperatures were a c

TABLE 1. Comparison of salmon catches and surface conditions at repeated sets at lat. 48° N. to 50° N. on 150° W., Summer 1956.

Station	Latitude	Date	Surface temperature (°C.)	Surface salinity (‰)
Celtic 7	48° N.	July 21	11.10	32.67
„ 33	48° N.	August 30	12.28	32.56
Celtic 8	49° N.	July 22	10.26	32.57
„ 34	49° N.	August 31	11.26	32.55
Celtic 9	50° N.	July 23	10.30	32.60
„ 35	50° N.	Sept. 1	11.46	32.87

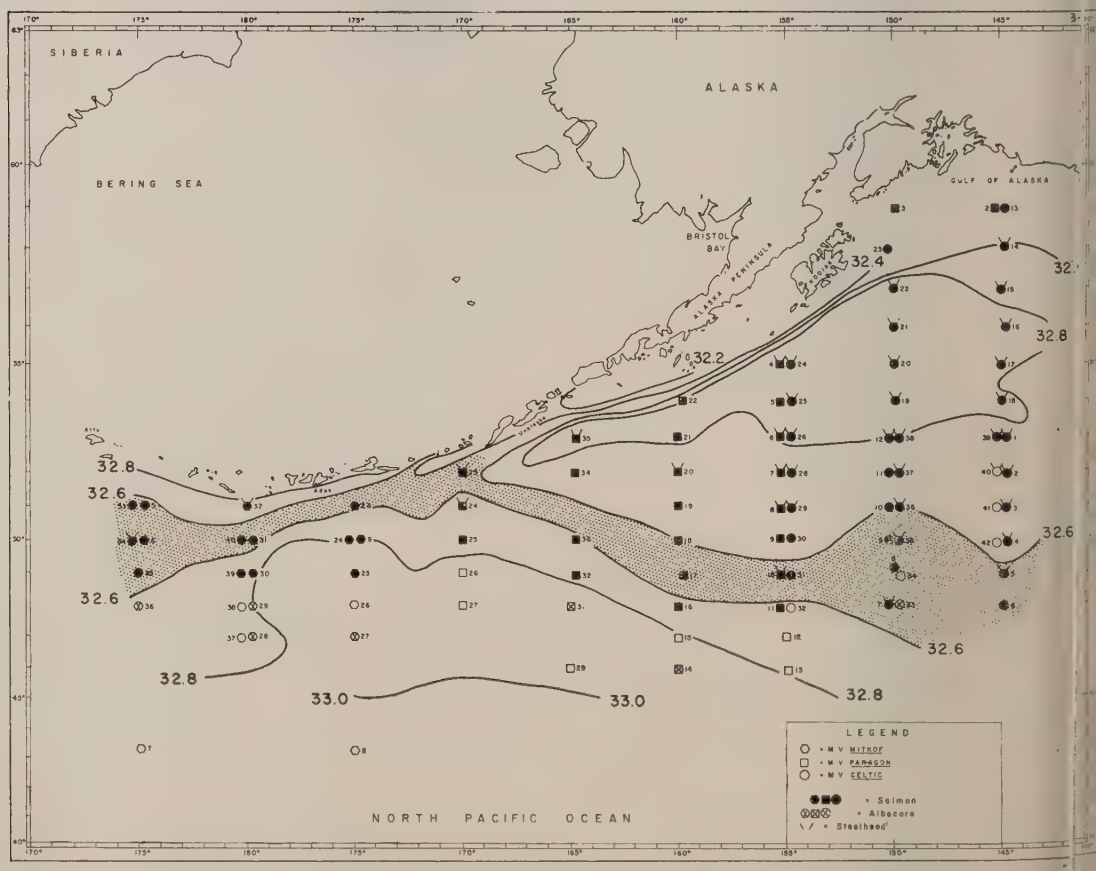


FIGURE 4. Surface salinity, Summer 1956, showing broad band of minimum salinity (32.6‰).

2. Comparison of salmon catches and surface conditions at repeated sets at lat. 48° N. to 50° N. on long. W., Summer 1956.

	Latitude	Date	Surface temperature (°C.)	Surface salinity (‰)	Total salmon catch
2	47° N.	July 28	11.60	32.74	0
peated)			—	—	—
1	48° N.	July 27	10.98	32.68	3
	48° N.	August 28	11.49	32.65	0
0	49° N.	July 26	9.70	32.58	36
	49° N.	August 26	10.90	32.58	19
	50° N.	July 25	9.14	32.69	40
	50° N.	August 23	11.32	32.72	51

tor in determining the southward limit of the in this area.

ce salinity. The surface salinity distribution ed in Figure 4 shows a broad band of minimum (32.6 ‰) extending from long. 175°E. eastlong the Aleutian Islands to long. 170°W., it trends southeastward to the coast of North a. This band of lower salinity water, which es a region of convergence, was not noticeably in the previous summer. It is believed to mnant of the previous summer's runoff from Askan coast, and in the process of recirculating the Gulf of Alaska gyral. The position of nd between long. 160°W. and 145°W. corregenerally to the southern limit of the salmon . This relationship, however, is not readily nt westward of long. 160°W. where catches ade south of the narrow band of minimum which extended to long. 175°E. The salinity ution provides an indication of the convergence current systems, but salmon were caught north, nd within the band of minimum salinity, and cise relationship between surface salinity and thern limit of salmon distribution is evident.

, although the sharp gradients of surface ies in the western Pacific where the cold, southward flowing Oyashio Current converges e warm, saline, northward flowing Kuroshio t provide indication of a major fishing ground, face gradients in the eastern Pacific are slight. mer the surface temperature gradients, although ced by vertical movement of cold water, are the result of latitudinal heating. The salinity nts are determined by the amount of dilute water recirculated counter-clockwise around lf of Alaska gyral. It is apparent that neither temperature nor surface salinity are closely related to the absence or abundance of salmon as determined by gillnet catches.

Vertical Sections of Temperature and Salinity in Relation to Salmon Distribution

Though surface conditions do not reveal the presence of any sharp gradients of temperature or salinity at the southern limit of salmon catches, the subsurface water structure does appear to show a direct relationship.

Two representative vertical sections of temperature and salinity have been selected for discussion—one southward of the Alaska Peninsula and the other southward of the Aleutian Islands.

Section on longitude 155°W. The vertical water structure on long. 155°W. constructed from data at *Celtic* stations 24 to 32 is shown in Figure 5. A similar water structure was found on long. 145°W., 150°W., 160°W. and 165°W.

At lat. 56°N., the characteristic downward slope of isolines near the continental shelf is implied by dashed lines. The temperature minimum (less than 3.5°C.) at 75 to 100 meters, typical of a water column in the Gulf of Alaska, is clearly evident between stations 24 to 31. Between stations 31 and 32, however, the almost vertical 4° and 5° isotherms indicate the presence of water of a southern origin. Salmon catches, at the respective stations, tabulated at the top of the figure, show that no salmon were caught in the surface gillnets at station 32.

As noted previously, surface temperatures do not indicate the presence of an abrupt change in temperature at depth. Nor can one say that the absence of salmon at station 32 was caused by higher surface temperatures because the large catches of 94 and 150 salmon at stations 25 and 26 were made in surface temperatures over 1°C. higher than the unproductive set at station 32.

The vertical salinity distribution also shows relatively uniform horizontal values between stations 24 to 30, but at stations 30 and 31 the isolines trend downward in the frontal zone.

Section on longitude 175°W. The other vertical section selected for discussion, on long. 175°W., is representative of the structure on long. 170°W., 180° and 175°E. Data from *New Glasgow* station 50 at lat. 51°31'N. and *Mitkof* stations 23 to 27 are presented in Figure 6. *New Glasgow* station 50 is not indicated, but has been utilized to show the southern extent of the coastal water as indicated by the 4°C. isotherm extending below 250 meters. Water characteristic

of the Gulf of Alaska is greatly compressed latitudinally and is present at *Mitkof* station 23. Between *Mitkof* stations 23 and 27 an intrusion from the west of water with a temperature minimum (less than 3.5°C.) below 150 meters is evident. The origin and extent of this water are discussed in the following section, Temperature-Salinity Relationships. Southw this intrusion, at station 27 where no salmo caught, the sharp downward trend of the 4° isotherms (similar to the temperature struc long. 155°W.) shows the subsurface front at lat.

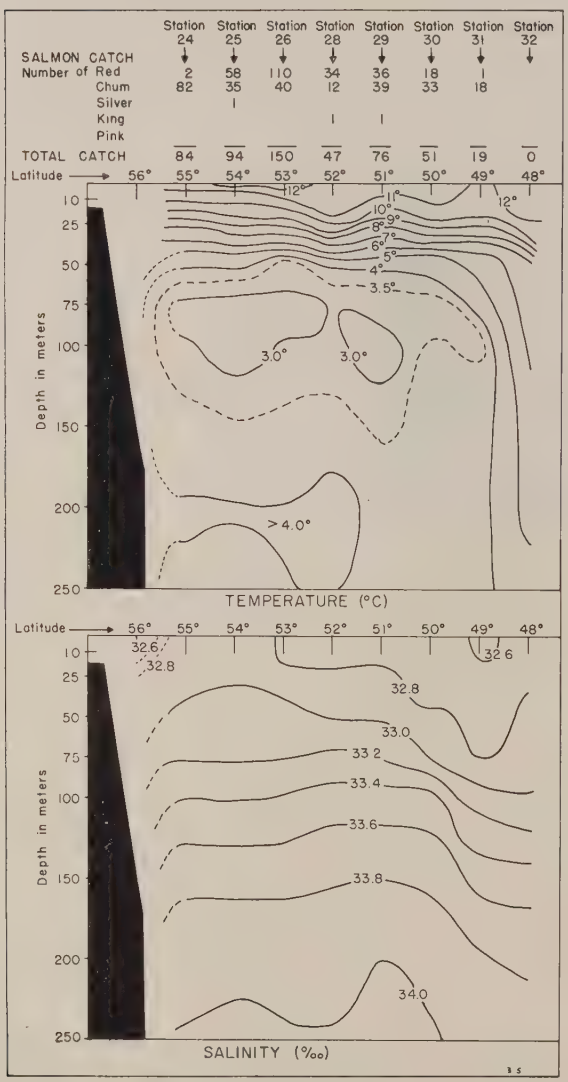


FIGURE 5. Comparison of salmon catches and vertical water structure on long. 155°W. (*Celtic* stations 24 to 32), showing temperature front associated with no salmon catches at lat. 48°N. (Alaska Peninsula shown in black).

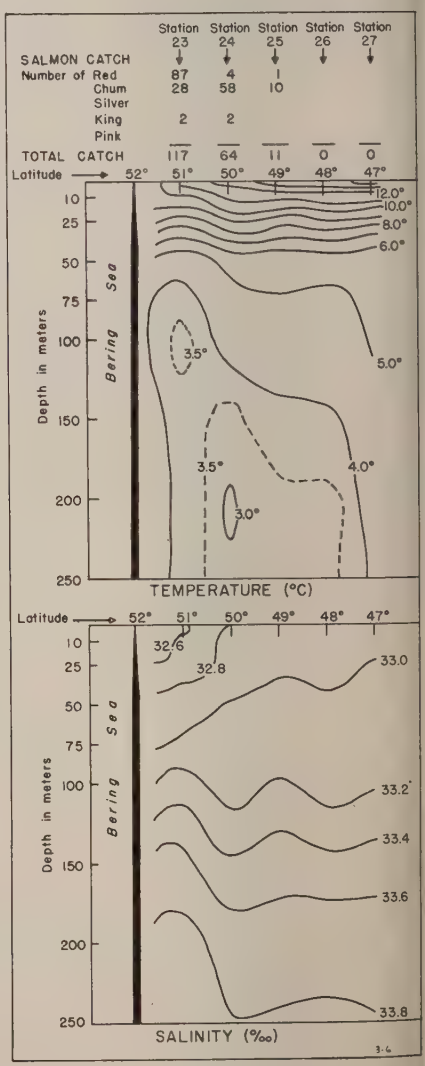


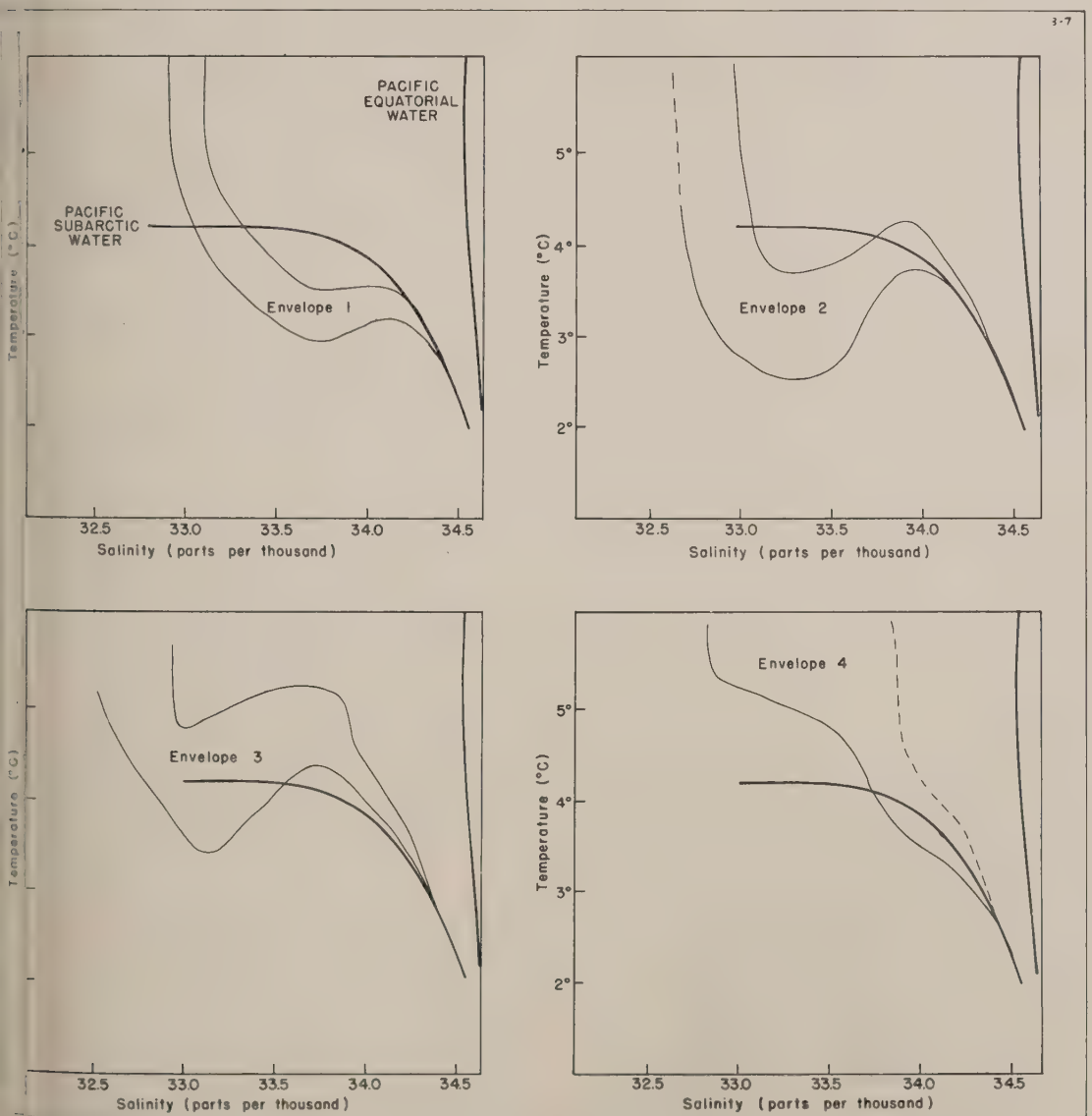
FIGURE 6. Comparison of salmon catches and vertic structure on long. 175°W. (*Mitkof* stations 23 to 27), front at lat. 47°N. (Aleutian Ridge shown in black).

salinity profile shows the surface dilution along uth side of the Aleutian Islands. Southward temperature minimum (3.5°C.) at station 23 alines trend downward; however, the intruded at stations 24 to 26 has resulted in a different structure than shown at long. 155°W.

perature-salinity relationships presented in the ng section are utilized to associate these water res with recognized water masses and to show graphic extent of the four types.

Temperature-Salinity Relationships

Sverdrup *et al.* (1942) utilized temperature-salinity relationships to identify water masses in the North Pacific Ocean. They defined Pacific Subarctic Water as water in which no salinity minimum is present and note that use of the term should be confined to the area north of lat. 45°N. The Pacific Central and Pacific Equatorial Water masses are also defined, both of which are characterized by the presence of a salinity minimum at depth, the latter water mass being considerably more saline for any given temperature.



RE 7. Temperature-salinity envelopes determined from *Mitkof*, *Celtic* and *Paragon* station data, showing three types of tbarctic Water (envelopes 1, 2 and 3) and Transition Water (envelope 4).

The extensive 1956 observations permit a more thorough examination of the water properties in the Subarctic Region than was possible for previous years. Values of temperature and the corresponding salinity within the ranges of 0°C. to 6°C. and 33‰ to 34.5‰ were plotted for each of the charter vessel stations shown in Figure 2. Individual station temperature-salinity curves have been enclosed within four envelopes. Values in the specified ranges exist at depth and have been selected as criteria of identification because they are relatively permanent compared to the transient surface values.

The envelopes are presented in Figure 7 and their relationships to the Pacific Subarctic and Pacific Equatorial curves can be inferred by the relative position of the envelopes between the two recognized curves.

The curves within envelope 1 are recognized by a slight temperature minimum accompanying salinities greater than 33.5‰ and usually occurring at 33.7‰ to 33.8‰. The temperature minimum occurs at 200 to 300 meters depth. The water identifi this envelope is believed to originate off the coast where in winter the low surface temper and the presence of ice permit an extensive v overturn of the water column and result in a tem ture minimum of about 0°C. at the above d The minimum temperature is gradually increa a result of mixing and diffusion during the mov of this water mass eastward from the Oyashio and reaches the 2°C. range in the central Pacif

The curves within envelope 2 are identified pronounced temperature minimum accompa salinities less than 33.5‰ and usually occurri 33.0‰. The minimum temperature occurs at 100 meters depth in the Gulf of Alaska where surface temperatures of 2–4°C. and mixing pe winter overturn down to the depth of the hal Tully (1957) has discussed the formation of thi mum temperature, and Doe (1955) denoted th having these characteristics to be the Mid-Gulf Although Doe's data were limited to the C

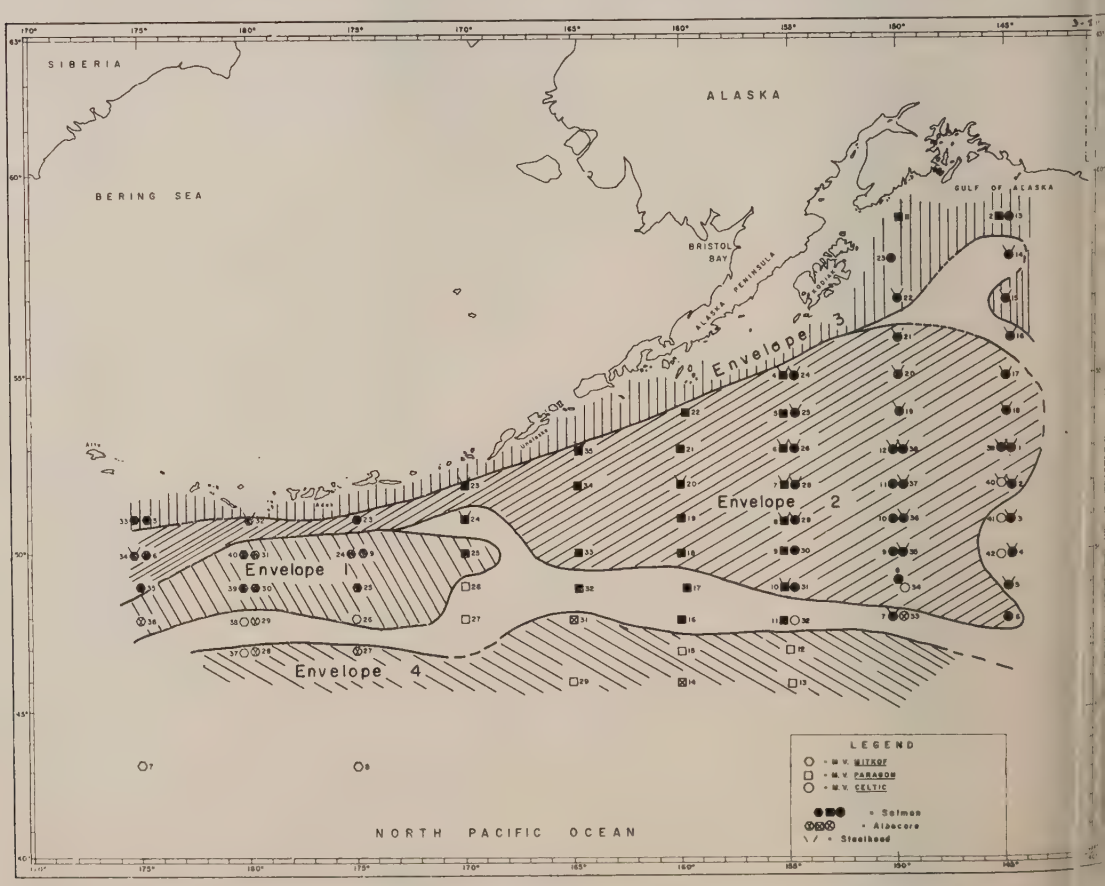


FIGURE 8. Geographical extent of water masses identified by temperature-salinity envelopes 1 to 4.

a, it appears that a curve of this type is also pres-
ong the Aleutian Chain.

e curves within envelope 3 result from the mixing
ters characteristic of envelopes 1, 2 and 4, and
off the North American coast. They are as-
ed with the westward flow of the Alaska current
the Aleutian Chain.

e curves within envelope 4 are characterized by
saline water and the absence of either a tem-
ure or salinity minimum which identify it as a
ition Water mass between the Subarctic and
c Central Water. If one considers the so-called
r front" to be the southern boundary of Sub-
Water, it would be indicated by stations having
aracteristic curve. Oxygen-salinity relationships
sed later in this report also show a marked change
tions identified by envelope 4.

e geographical extent of the stations identified
e four envelopes are shown in Figure 8. There
me stations at which lateral mixing has prevented
-S curves from falling within one of the charac-
c groups.

e southern extent of salmon catches between
145°W. and 165°W. coincides very closely with
rea of mixing between envelopes 2 and 4. No
n were caught at stations identified by envelope

stward of long. 165°W., where no clear relation-
existed between the catches and the surface tem-
ure or salinity, it is apparent that all catches were
at stations identified by envelopes 1, 2, or 3.
all catches were made in water identified as
ctic, and none were made in the Transition
r mass identified by envelope 4.

tical section of silicate distribution near longitude
W. Only temperature and salinity observations
made aboard the *Mitkof*, *Celtic* and *Paragon*, but
chemical constituents, which show further differ-
in the environments north and south of the
face temperature front, were analyzed aboard
ew Glasgow.

Glasgow stations 58 to 64 are shown in Figure
lthough values of phosphate, silicate, nitrate and
ere obtained, only the silicates show any appreci-
change north and south of the front. Figure 9
a vertical section of silicates from the surface to
0 meters. In the upper 30 meters, from the Alaska
sula to lat. 48°N., the values range between 25
30 microgram-atoms per liter, but immediately
of lat. 48°N. the values decrease to less than 20,
re less than 10 microgram-atoms per liter at lat.

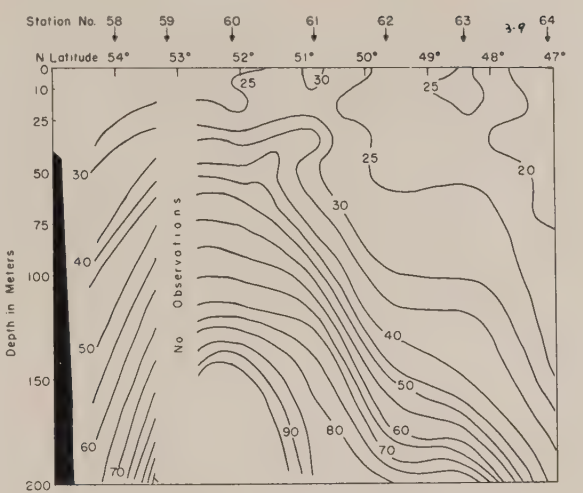


FIGURE 9. Vertical silicate distribution (μg. at./l.) (*New Glasgow* stations 58 to 66), showing the change in horizontal concentrations at approximately lat. 50°N. (Alaska Peninsula shown in black).

45°N. Below 50 meters the 25 microgram-atom per liter isoline dips sharply downward in a manner similar to the 4°C. and 5°C. isotherms in Figure 6.

Oxygen-Salinity Relationships

Additional evidence of a different environment north and south of the frontal zone can be shown by oxygen-salinity relationships at *New Glasgow* stations 58 to 64 and 50 to 45 (Fig. 2). The relatively saturated oxygen values in the surface layer do not show any significant differences, but at depth, oxygen-salinity relationships (Fig. 10) show that from the Alaska Peninsula to lat. 49°39'N. (stations 58–62) the relationships are quite similar and markedly different from those at stations 63 and 64, which are south of the temperature front.

The oxygen-salinity relationships at stations 50 and 49 (north of front at approximately long. 155°W.) are very similar to those at stations 58 to 62 (north of front at approximately long. 175°W.), indicating an east-west continuity of water properties. The values at stations 48 to 46 must be considered as transitional ones, but at station 45 (south of front at approximately long. 173°W.), the relationships are almost identical to those at stations 63 and 64 (south of front at approximately long. 173°W.). Although the separation of the two environments is not as sharp at long. 173°W. as at long. 155°W. because of oxygen-salinity relationships in the water intruded from the west (noted in the discussion of the vertical sections at long. 175°W.), the latitudes at which a change in oxygen-salinity relationships occurs coincide with the latitudes of the

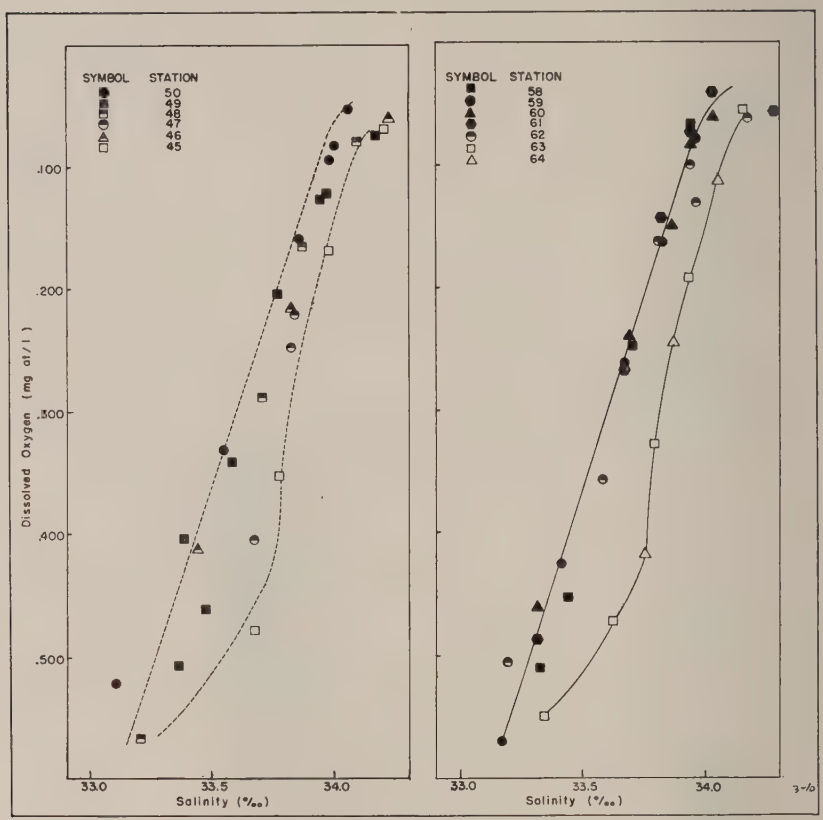


FIGURE 10. Oxygen-salinity relationships for *New Glasgow* stations, showing a marked change in relationships north of temperature front (dark symbols) and south of front (open symbols) at long. 169°W. to 175°W. and long. 151°W. to 158°W. (see Figure 2 for station locations).

temperature fronts at these approximate longitudes as shown previously by *Mitkof* and *Celtic* data.

SUMMARY OF *MITKOF*, *PARAGON* AND *CELTIC* DATA

Before comparing the results of our fishing cruises to those of the Japan Fisheries Agency, and considering the maximum southern extent of the salmon distribution, it would be advantageous to summarize the relationships between the salmon distribution and oceanographic conditions revealed thus far.

The results of the experimental fishing in July and August, 1956, aboard the chartered vessels *Mitkof*, *Paragon* and *Celtic* have shown that immature salmon were caught north of approximately lat. 48°N. from long. 145°W. to the westward limit of the area of investigation, long. 175°E.

Above lat. 48°N., the catches as reported by Hanavan and Tanonaka (1959) varied from one to over one hundred salmon. The largest catches were made south of the Aleutian Islands at *Mitkof* stations 32 and 33 (Figure 1) where 197 and 323 salmon were c[illegible]. At station 32, 162 of these were red salmon (*rhynchus nerka*) and at station 33, 235 were red a[illegible] on. These represent about one-fourth of the[illegible] red salmon catch at the 131 fishing sets made by [illegible] vessels. Future observations adjacent to and [illegible] the Aleutian Islands are required to determine [illegible] tionships between the environment and these un[illegible] ly large red salmon catches.

The uncertainty of a depth of " no net motion [illegible] the boundary conditions imposed by the land [illegible] compromise the usual method of ascertaining s[illegible] currents by the dynamic topography. Because [illegible] istic velocities cannot be ascertained, surface cu[illegible] have not been discussed. The intrusion of [illegible] surface water flowing westward along the [illegible] Peninsula, the interaction of water north and [illegible] of the Aleutian passes, and the fast-moving [illegible] Aleutian storms all affect the surface conditions [illegible] ing the basic subsurface features. These fe[illegible] however, are relatively permanent, slow-movin[illegible]

ive of local areas that may serve as a guide to grating salmon.

southern limit of the salmon catches in the area the summer coincided with the subsurface ature front separating Subarctic Water, as ined by subsurface temperature-salinity rela-ps, from Transition Water. Although the es as presented clearly define subwater masses Subarctic Region, no attempt has been made e them as Oyashio, Deep or Coastal because s not sufficient data for a permanent classifica-

gen-salinity relationships and silicate distribu- ave been utilized to show that the subsurface ment north of the front is relatively uniform gnificantly different from the environment to ith. This boundary at lat. 48°N., however, ly define the southern limit of the salmon dis- on during the summer.

SOUTHERN EXTENT OF SALMON DISTRIBUTION

e spring of 1956, two other investigations ob- data that show a further southward extent of distribution. These were the Japan Fisheries studying the salmon distribution south of lat. and the Pacific Oceanic Fisheries Investiga- Honolulu, Hawaii, investigating the distribu- albacore tuna, *Germo alalunga* (Bonnaterre).

N Catches by the Japanese Fisheries Agency NG, Summer 1956

results of a Japan Fisheries Agency salmon operation in 1956 show that lat. 48°N. was not imate southern limit of the salmon distribution spring of 1956 in the western and central . Maeda (1959) reported the results of this excel- dy on the salmon fishing grounds between lat. and 46°N. and long. 155°E. and 175°W. during

3. Southern limit of salmon catches between long. E. and 175° W., Spring 1956 (Maeda, 1959).

Species	Period	Latitude
almon (*Oncorhynchus nerka*)	Early May	43° N.
	Late May	45° N.
	Early June	46° N.
salmon (*O. keta*)	Early May	42° N.
	Late May	45° N.
	Early June	46° N.
salmon (*O. gorbuscha*)	Late May	46° N.
salmon (*O. kisutch*)	Early May	42° N.

May, June and July, 1956. He compared the salmon catches with water temperature, transparency and sea surface currents, and noted that salmon migrating south of lat. 46°N. become concentrated around a cold water mass near long. 167°E. as the water temperature rises and that the waters south of lat. 46°N. are the best fishing areas in spring. The southern limits of the salmon catches have been reproduced in Table 3 and show that salmon were caught as far south as lat. 42°N. in May, but by June none were caught south of lat. 46°N.

Salmon Catches by Pacific Oceanic Fishery Investigations—Spring 1956

The southern limit of salmon catches eastward of the Japanese fishing area is indicated by a total catch of four pink salmon by the United States Fish and Wildlife Service vessel *Charles H. Gilbert* at lat. 41°28′N., long. 165°18′W. and lat. 41°30′N., long. 164°33′W. on April 22 and 23, 1956 (Otsu, 1956). These salmon were caught at the northernmost part of the *Gilbert* cruise, and none were captured south of this latitude.

Oceanographic Conditions 1958

Since hydrographic casts were not made aboard the Japanese vessels or the *Gilbert*, the oceanographic features near lat. 40°N. in 1956 are not known. It can, however, be shown by previous and more recent data that the subsurface features that have been discussed are relatively permanent. Thus, the extensive oceanographic cruises in the North Pacific in 1958 afford a good indication of the continuity of oceanographic features across the ocean, and permit comparison of

Table 4. Sources of 1958 oceanographic data utilized in Figure 11.

Vessel	Agency
M.V. *Pioneer*	Bureau of Commercial Fisheries Biological Laboratory, Seattle, Washington (Favorite and Pedersen, 1959b).
R.V. *Hugh M. Smith*	Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii[1].
C.N.A.V. *Whitethroat*	Pacific Oceanographic Group, Fisheries Research Board of Canada, Nanaimo, British Columbia (Pacific Oceanographic Group, 1958).
R.V. *Ryofu-maru*	Japan Meteorological Agency, Tokyo, Japan[1].
R.V. *Soyo-maru*	Tokai Regional Fisheries Research Laboratory, Tokyo, Japan (Tokai Regional Fisheries Research Laboratory, 1959).

[1] Unpublished.

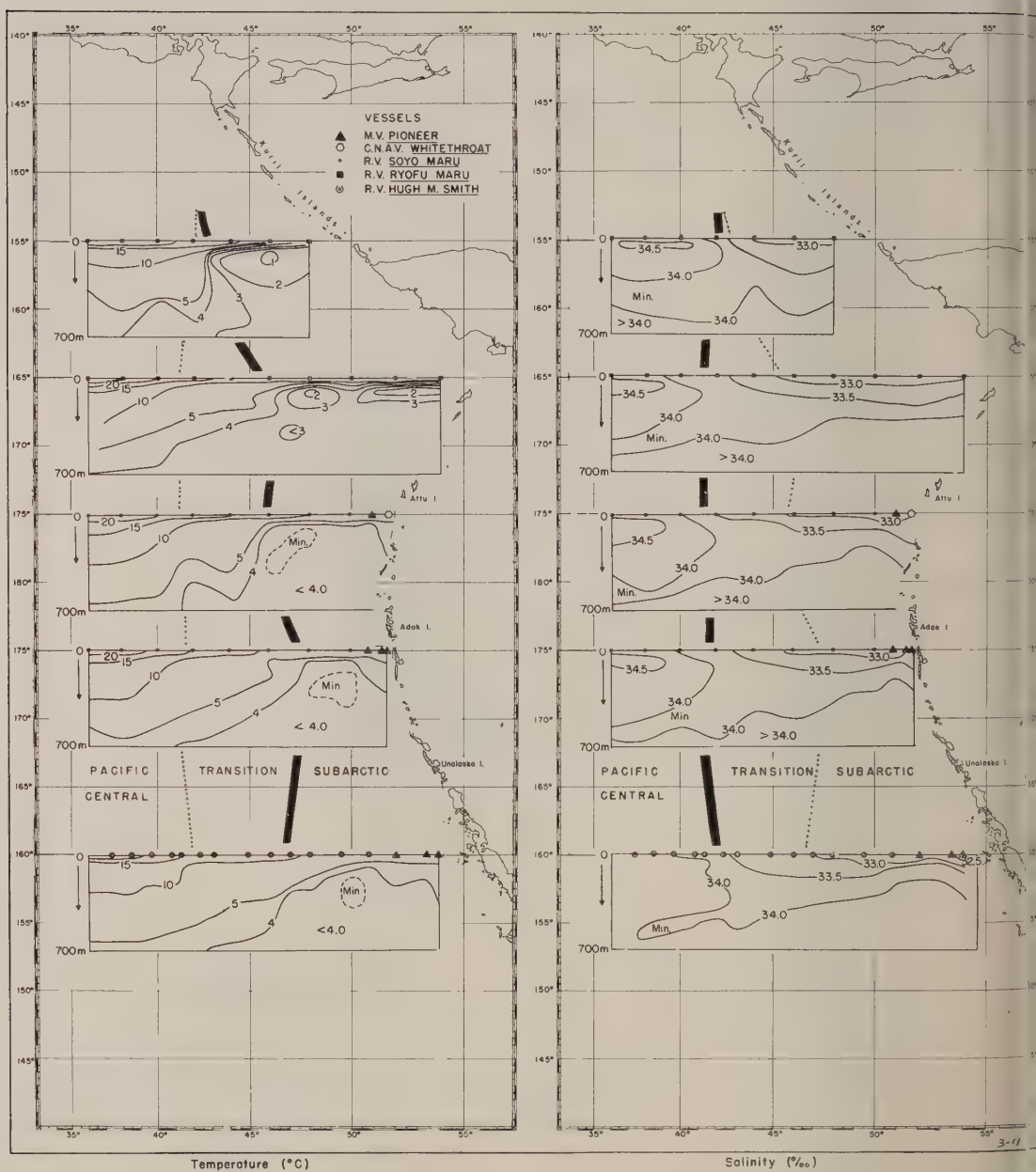


FIGURE 11. Vertical sections of temperature and salinity along long. 160°W., 175°W., 175°E., 165°E. and 155°E., Sum 1958, showing the extent of the Subarctic, Transition and Central Pacific Regions. Discontinuous black line inserted bet the temperature sections shows proposed southern limit of salmons during summer; similar line between salinity sec shows proposed maximum southern limit of salmons. (Temperature contour interval: 0° to 5°C.—1°C.; 5° to 25°C.— Salinity contour interval: 0.5‰.)

the fishing results to oceanographic features. Sources of these oceanographic data are presented in Table 4. Figure 11 shows vertical profiles of temperature and salinity to a depth of 700 meters on long. 160°W. and 175°W., and 175°E., 165°E. and 155°E. Although the detail permitted by the 1956 oceanog data in the northeastern Pacific cannot be sho significant features are clearly seen.

The discontinuous black line inserted betwe

sections of temperature indicate the approxi-
osition of the temperature front associated with
. isotherm previously discussed. The crowd-
he isotherms near the surface northward of this
ows the very shallow surface layer character-
the Subarctic Region. It should be noted
long. 160°W. the front occurs at lat. 47°N.,
s in 1956 it was at lat. 48°N. This has been
by a further eastward intrusion of water charac-
of envelope 1 discussed previously, which can-
identified in this gross presentation. At long.
and 175°E., the front occurs at lat. 46°N.
Maeda (1959) reported large salmon catches in
956.

solid bars inserted between the vertical salinity
show the northward extent of the salinity
m characteristic of central Pacific water. The
l 34‰ salinity isohaline denoting the salinity
ccurs at lat. 41°N. to 42°N. and corresponds to
uthern limit of salmon catches reported by the
and Japanese vessels in April and May in 1956.

area between the temperature and salinity
is considered to be the Transition Region. In
stern Pacific the fronts coincide and form a
nvironmental boundary, whereas in the central
they are about 300 miles apart.

DISCUSSION AND CONCLUSIONS

her the oceanic extent of the distribution of
s nor the factors which control their move-
during the years they spend in the ocean are
. Comparisons of oceanographic conditions
lmon catch data from the *Mitkof*, *Celtic* and
n have shown that in the eastern North Pacific
north of lat. 45°N. surface conditions did not
te the presence or abundance of salmon.

non catches at lat. 42°N. in the western North
in May reported by Maeda (1959) and the
catch by the *Gilbert* at lat. 41°30′N., long. 165°W.
te that the Transition Region, identified by the
e of either a temperature or salinity minimum,
onstitute a preferable environment for salmon in
, even possibly at depth in summer for immature
n. The salinity front at approximately lat.
. as defined by the almost vertical 34‰ isohaline,
denote the maximum southern limit of salmon
outlon in midocean. Although there is an ap-
northward movement of salmon in late May to
5°N. and 46°N. in the western Pacific there is no
ce to show that the salmon were not present at
southward of these latitudes and merely avoided
warm surface layer. In fact, Hashimoto and Maniwa (1959), using echo-sounding equipment in the western Pacific, have shown that salmon do not necessarily migrate to the surface at night (thus making them susceptible to capture in gillnets) and in some instances remain at 30 to 50 meters depth.

The southern limit of gillnet catches in summer at lat. 46°N. in the western Pacific reported by Maeda (1959) and at lat. 48°N. in the eastern Pacific shown by Hanavan and Tanonaka (1959) occurred at the subsurface temperature front which separates Subarctic Water, as identified at depth by a temperature minimum (<4.0°C.) rather than by surface dilution, from Transition Water. Northward of this front and thus in the Subarctic Region, the 4°C. isotherm forms a very shallow surface layer across the North Pacific. The shallow surface layer may confine food organisms nearer to the surface. Maeda *et al.* (1957) have shown that plankton concentrated near the surface by a thermocline has a close relationship to the migration of salmon. Then too, this layer is characterized by low salinity values reflecting dilution by runoff from coastal areas that may aid the salmon in their migrations. Either of these conditions could explain the presence of salmon in the northern area.

Lack of information concerning spawning and feeding migrations prevents making any specific conclusions as to the actual cause of a northward migration in spring—whether avoidance of the warmer surface temperatures to the south or the consequences of spawning or feeding migrations would cause the salmon to enter a different environment in which they may be forced closer to the surface. This would make them more susceptible to capture in the surface gillnets, and would account in part for the sudden appearance in spring of salmon near the temperature front and explain the apparent absence of salmon southward of the front in summer.

LITERATURE CITED

Barnaby, Joseph T. 1952. Offshore fishing in Bristol Bay and Bering Sea. *U.S. Fish and Wildlife Service, Special Scientific Report—Fisheries*, No. 89, 30 pp.

Doe, L. A. E. 1955. Offshore waters of the Canadian Pacific Coast. *Journal Fisheries Research Board of Canada*, 12(1): 1-34.

Favorite, Felix, and Cuthbert M. Love. 1957. Northeast Pacific Ocean and Gulf of Alaska physical and chemical data, summer and fall 1955. *University of Washington* (Seattle), *Department of Oceanography, Special Report*, No. 28, 88 pp. (processed).

Favorite, Felix, and Glenn Pedersen. 1959a. Bristol Bay oceanography, August-September 1938. *U.S. Fish and Wildlife Service, Special Scientific Report—Fisheries*, No. 311, 231 pp.

Favorite, Felix, and Glenn Pedersen. 1959b. North Pacific and Bering Sea oceanography 1958. *U.S. Fish and Wildlife Service, Special Scientific Report—Fisheries*, No. 312, 230 pp.

FAVORITE, FELIX, JOHN SCHANTZ AND CHARLES HEBARD. 1961. Oceanographic observations in Bristol Bay and the Bering Sea 1939–1941 (USCGT *Redwing*). *U.S. Fish and Wildlife Service, Special Scientific Report—Fisheries*, No. 381, 323 pp.

FLEMING, RICHARD H. 1955. Review of the oceanography of the northern Pacific. *Bulletin International North Pacific Fisheries Commission*, 2, 43 pp.

HANAVAN, MITCHELL G., AND GEORGE K. TANONAKA. 1959. Experimental fishing to determine distribution of salmon in the North Pacific Ocean and Bering Sea, 1956. *U.S. Fish and Wildlife Service, Special Scientific Report—Fisheries*, No. 302, 22 pp.

HARTT, ALLAN C. 1959. Movement of salmon in the North Pacific Ocean and Bering Sea as determined by tagging, 1956–1958. *University of Washington* (Seattle), *Fisheries Research Institute, Circular*, No. 106, 99 pp. and *Appendix*. (Processed.)

HASHIMOTO, T., AND Y. MANIWA. 1959. Fish-finding on the salmon fishing grounds in the North Pacific Ocean. *Modern Fishing Gear of the World* (FAO), Fishing News (London), p. 523–524.

HOKKAIDO UNIVERSITY. 1957. Data record of oceanographic observations and exploratory fishing, No. 1. Hokkaido University (Hakodate), Faculty of Fisheries, 247 pp.

INTERNATIONAL NORTH PACIFIC FISHERIES COMMISSION. 1955. Bulletin No. 1, 138 pp. (Vancouver, Canada.)

JAPAN AGRICULTURAL TECHNICAL ASSOCIATION. 1954. Oceanographic observation data northern waters 1885–1953. Nogyo Kijitsu Kyokai, 556 pp. (In Japanese.)

LOVE, CUTHBERT M. 1957. Oceanographic observations in the North Pacific aboard vessels of the U.S. Fish and Wildlife Service, summer and fall, 1956. *University of Washington* (Seattle), *Department of Oceanography, Special Report*, No. 27, 42 pp. (processed).

LOVE, CUTHBERT M. 1959. Physical and chemical data, North Pacific Ocean, Gulf of Alaska, and Bering Sea, summer, 1956. *University of Washington* (Seattle), *Department of Oceanography, Special Report*, No. 31, 13 pp., (216) p. tables. (Processed.)

MAEDA, TATSUAKI. 1959. Study on the salmon fishing grounds in the North Pacific Ocean. *Bulletin Faculty of Fisheries, Hokkaido University* (Hakodate), 9(4) : 268–282.

MAEDA, TATSUAKI, MOTOKAZU UENO AND ICHIRO SAITO. 1957. Studies on Deep Scattering Layer off the west coast of Kamchatka Peninsula. *Bulletin Faculty of Fisheries, Hokkaido University* (Hakodate), 7(4) : 284–290.

MANZER, J. I. 1958. Salmon distribution and abundance in the northeast Pacific, 1956 and 1957, with some comparisons with other regions of the North Pacific and the Bering Sea. *Fisheries Research Board of Canada, Manuscript Report Series* (*Biological*), No. 656, 38 pp. (processed).

MISHIMA, SEIKICHI, AND SATOSHI NISHIZAWA. 1955. Report on hydrographic investigations in Aleutian waters and the southern Bering Sea in the early summers of 1953 and 1954. *Bulletin Faculty of Fisheries, Hokkaido University* (Hakodate), 6(2) : 85–124.

NAKAI, ZINZIRO, AND KOJI HONJO. 1954. A preliminary report on surveys of plankton and salmon stomach contents from the North Pacific, 1952. *Tokai Regional Fisheries Research Laboratory* (Tokyo), *Special Publication*, No. 3 : 6–12.

OTSU, TOMIO. 1956. Cruise report, M/V *Charles H. Gilbert*, cruise 27. *U.S. Fish and Wildlife Service, Pacific Ocean Fi... Investigations*. 1 p. (processed).

PACIFIC OCEANOGRAPHIC GROUP. 1957. Physical, ... and plankton data record, North Pacific survey, ... September 2, 1956, with Appendix I, Marine salmon ... tory fishing surveys, May 22-September 12, 1956. ... Research Board of Canada, 191 pp.

PACIFIC OCEANOGRAPHIC GROUP. 1958. Physical and ... data record, North Pacific surveys, Western Aleuti... Bering Sea, June 27 to August 14, 1958. *Fisheries Resea... of Canada, Manuscript Report Series* (*Oceanographic and Limn...* No. 28, 104 pp.

POWELL, DONALD E., AND ALVIN E. PETERSON. 1957. ... mental fishing to determine distribution of salmon in t... Pacific Ocean, 1955. *U.S. Fish and Wildlife Service S... Scientific Report—Fisheries*, No. 205, 30 pp.

SCHAEFERS, EDWARD A., AND FRANCIS M. FUKUHARA. 19... shore salmon explorations adjacent to the Aleutian... June-July 1953. *U.S. Fish and Wildlife Service, Commercial ... Review*, 16(5) : 1–20.

SVERDRUP, H. U., MARTIN W. JOHNSON AND RICHARD H... ING. 1942. The oceans : their physics, chemistry and ... biology. Prentice-Hall (New York), 1087 pp.

TAGUCHI, KISABURO. 1955. The movement of water m... the seas of West Aleutian Islands and off east coast of Kam... salmon fishing ground. I. Inference from the distribu... water temperature, water colour, and transparency. ... *Japanese Society of Scientific Fisheries* (Tokyo), 20(9) : 77...

TAGUCHI, KISABURO. 1956. A report of drift-bottle sur... Kamchatka, USSR in 1940 and 1941. *Bulletin Japanes... of Scientific Fisheries* (Tokyo), 22(7) : 393–399.

TAGUCHI, KISABURO. 1957. The seasonal variation of t... fishing area of salmon and the movements of water m... the waters of Western North Pacific—I, II and III. ... *Japanese Society of Scientific Fisheries* (Tokyo), 22(9) : ... and 515–521; 22(10) : 609–617.

TAGUCHI, KISABURO, AND YUTAKA HIROSE. 1954. ... currents and oceanographical condition in the northern ... salmon fishing ground. *Bulletin Japanese Society of ... Fisheries* (Tokyo), 20(7) : 576–580.

TAGUCHI, KISABURO, AND YOSHIRO SHOJI. 1955. The ... ment of water masses in the seas of West Aleutian Isla... off east coast of Kamchatka salmon fishing grour... Inference after observation by the current meters in tw... *Bulletin Japanese Society of Scientific Fisheries* (Tokyo), ... 780–782.

TOKAI REGIONAL FISHERIES RESEARCH LABORATORY. ... IGY physical and chemical data by the R.V. Soyo-m... July–14 September 1958. Tokai Regional Fisheries R... Laboratory (Tokyo), 17 pp.

TULLY, J.P. 1957. Some characteristics of sea water str... *Proceedings of the Eighth Pacific Science Congress*, Vol. III, ... *graphy*, p. 643–661.

WATANABE, NOBUO. 1954. A report on oceanographi... vestigations in the salmon fishing grounds of the North ... 1952 and 1953. *Tokai Regional Fisheries Research La...* (Tokyo), *Special Publication*, No. 3 : 1–5.

OCEANOGRAPHY

by Felix Favorite and B. A. Morse

Field Work

P sical, chemical and biological observations, ir to those obtained in previous years, were c aboard chartered vessels *Paragon*, *Marine View*, i *Windward* at fishing locations (Fig. 19).

Z plankton investigations were conducted aboard JSC&GS vessel *Pioneer* during a cruise from lulu to the Aleutian Islands and return (Fig. . These observations will permit comparison of oundance of food organisms in salmon waters ward of lat. 40°N.) with the food organisms t region to the southward, and investigations of pe and abundance of organisms in the Inter- te Water. The latter water mass, identified salinity minimum ($<34.0^0/_{00}$) occurring at between the surface lens of Pacific Central a and the Deep Water (Favorite and Hebard,), is believed to originate in the Okhotsk Sea d nay influence the distribution and movements of the salmons. Although the water mass exists at depth, it is continuous across the North Pacific Ocean southward of latitude 40°N. *In situ* temperatures of 4° to 8°C., and dissolved oxygen values of .2 to .4 mg. at./L seem to provide an acceptable salmon environment.

Physical Oceanography

The oceanographic data collected during 1939 to 1941 in Bristol Bay (Favorite *et al.*, 1961) have been analyzed. A description of oceanographic conditions and features in the Bay has been completed and will be included in the Joint Report on Oceanography being prepared for the Committee on Biology and Research. The general counter-clockwise circulation in the Bay is widely recognized, but there appears to be an active upwelling zone at the entrance of the Bay between Cape Peirce and Port Moller. This is reflected in data collected during Summer, 1940, by

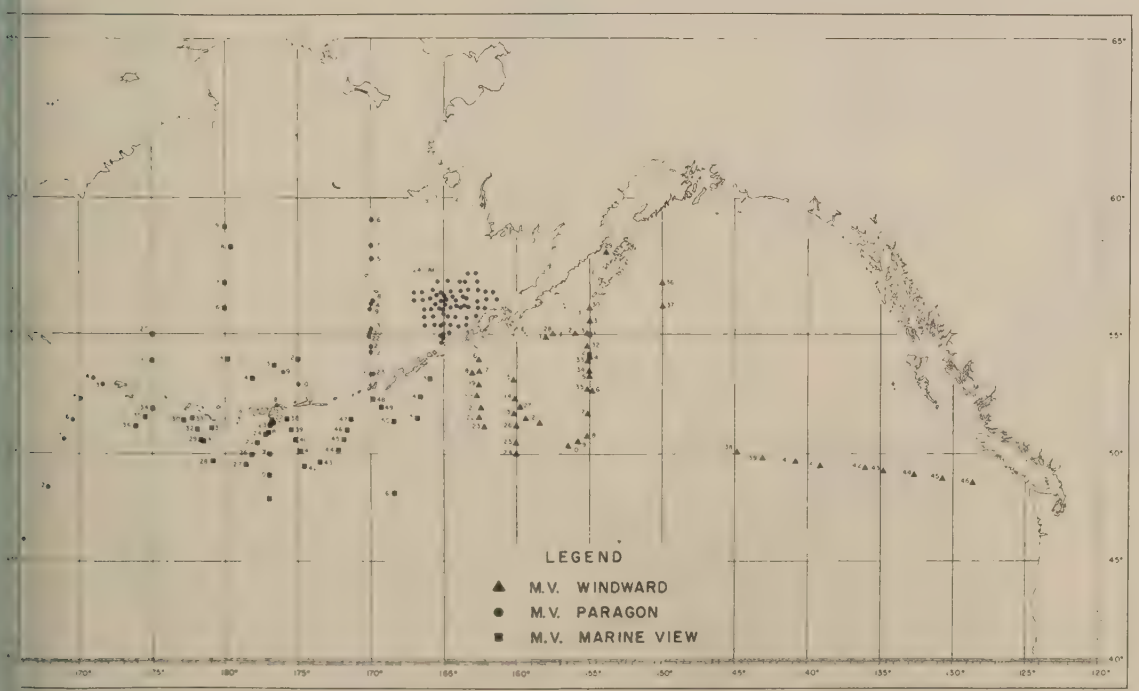


Figure 19. Oceanographic stations, 1961.

nternational North Pacific Fisheries Commission, Annual Report 1961, ancouver, Canada, 1963, p. 102-105.

Chum Mesh size						Pink Mesh size									
5¼	4½	3⅞	3¼	2½	Total	5¼	4½	3⅞	3¼	2½	Total	Silver	King	Total salmon catch	Steelhead
0	2	0	0	0	2	0	0	0	0	0	0	0	0	7	0
5	18	0	0	0	23	0	0	0	0	0	0	0	0	46	0
1	11	0	0	0	12	0	0	0	0	0	0	0	0	129	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	6	0	0	0	6	0	0	0	0	0	0	0	0	25	0
0	1	0	0	0	1	0	0	0	0	0	0	0	1	18	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0
0	8	0	0	0	8	0	0	0	0	0	0	0	1	74	0
4	11	0	0	0	15	0	0	0	0	0	0	0	1	46	0
18	41	0	1	0	60	0	4	0	0	0	4	0	4	322	0
3	15	1	0	0	19	0	1	1	0	0	2	0	0	90	0
1	11	0	0	0	12	0	1	0	0	0	1	0	0	152	0
8	18	0	0	0	26	0	5	1	0	0	6	0	0	48	0
0	7	0	0	0	7	0	2	0	0	0	2	0	0	59	0
0	5	0	0	0	5	0	0	0	0	0	0	0	0	37	0
5	36	1	0	0	42	0	10	0	1	0	11	0	4	203	0
4	21	0	0	0	25	1	17	1	0	0	19	0	0	86	0
1	10	2	0	0	13	4	6	0	0	0	10	0	0	75	0
7	52	6	1	0	66	1	15	1	0	0	17	0	0	154	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
2	12	0	0	0	14	0	1	0	0	0	1	0	0	169	0
1	7	0	0	0	8	0	2	1	0	0	3	0	0	47	0
60	292	10	2	0	364	6	64	5	1	0	76	0	11	1813	0
72	622	272	113	2	1081	15	21	2	0	0	38	46	1	1335	32
224	1656	120	52	6	2058	55	775	48	6	0	884	39	9	5083	61
296	2278	392	165	8	3139	70	796	50	6	0	922	85	10	6418	93
95	1191	183	153	127	1749	35	719	66	11	2	833	662	37	5569	33
60	292	10	2	0	364	6	64	5	1	0	76	0	11	1813	0
155	1483	193	155	127	2113	41	783	71	12	2	909	662	48	7382	33
451	3761	585	320	135	5252	111	1579	121	18	2	1831	747	58	13800	126

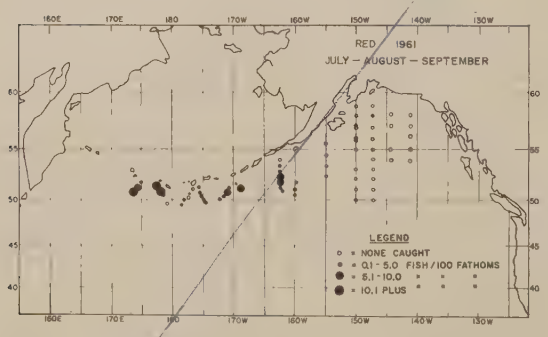


FIGURE 17. Juvenile red salmon relative abundance, July, August, and September 1961—1 winter-in-the-sea fish taken in 2-1/2 and 3-3/4-inch mesh nets.

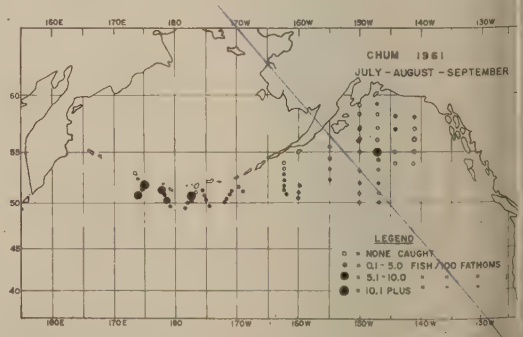


FIGURE 18. Juvenile chum salmon relative abundance, July, August, and September 1961—2-year-old fish taken 2-1/2 and 3-1/4-inch mesh nets.

n surface salinity values (31.8 and 31.9‰) shown igure 21, and the feature is found for all years in ch adequate data are available in this area.

he Joint Report on Oceanography will summarize ditions, features, and processes revealed through lyses of data collected by members of INPFC and er agencies. During the past year, we have estigated the possibility of predicting oceanographic ditions in salmon waters. Volume transport a from 0 to 1200 meters computed from hydro- phic observations made during Summer 1958 were rpolated to obtain values across the boundaries ° squares of latitude and longitude over the North ific Ocean northward of latitude 35°N. These ues were compared with geostrophic mass trans- ts computed from wind stress measurements for y and August (Fofonoff, 1960) which were treated the same manner. For convenience, transport the westward flowing Alaska Boundary Current was contained south of the Aleutian Islands until longitude 175°E. The general agreement in zonal and meridional components of transport (Figs. 22 and 23) is encouraging, but improvements in both methods

FIGURE 20. Location of zooplankton observations made aboard the USC and GS vessel *Pioneer* during September and October 1961.

FIGURE 21. Surface salinity, Summer 1960.

of computation are necessary before they can be effectively compared, or the latter considered a reliable method of predicting conditions. First, a valid reference level for the volume transports must be ascertained by means of direct current measurements; and second, several theoretical considerations in the mass transport data require further study. One important consideration is the fact that the geostrophic mass transport for each month is computed from wind stress derived from average sea level pressures that occurred during that month, and the induced inertia of the ocean is not carried over to the next month. It should be pointed out that the data were not derived specifically for the above predictive purpose. Nevertheless, they are a significant contribution to our knowledge of the possible effects of wind stress on the circulation, and could permit presentations of oceanic transport across the Pacific Ocean impossible to obtain by research vessels. Since the transport data do not reveal the extent of individual water masses discussed in previous annual reports, it may be necessary to devise a system of moored buoys to obtain this information.

Considerable progress has been made on the Joi Report on Oceanography and we anticipate that t manuscript will be completed by March 1962.

Instrumentation. As we add to our knowledge oceanographic conditions and possible relationshi to the salmons, it becomes increasingly more desirab to determine the *in situ* conditions while aboard t vessel so that particular environments may be soug out, or changes in environmental conditions betwe fishing sets are recognized. Since our experimen in 1958 to ascertain surface salinities by means of conductivity device towed astern of the vessels, v have tried to find an inexpensive, compact, reliab device that would permit analysis of water sampl aboard the chartered vessels which usually do n have laboratory space. The new IMC salinomet presently used for analyses in the laboratory capable of shipboard operation, but the unit is t expensive to permit placing one aboard each charter fishing vessel.

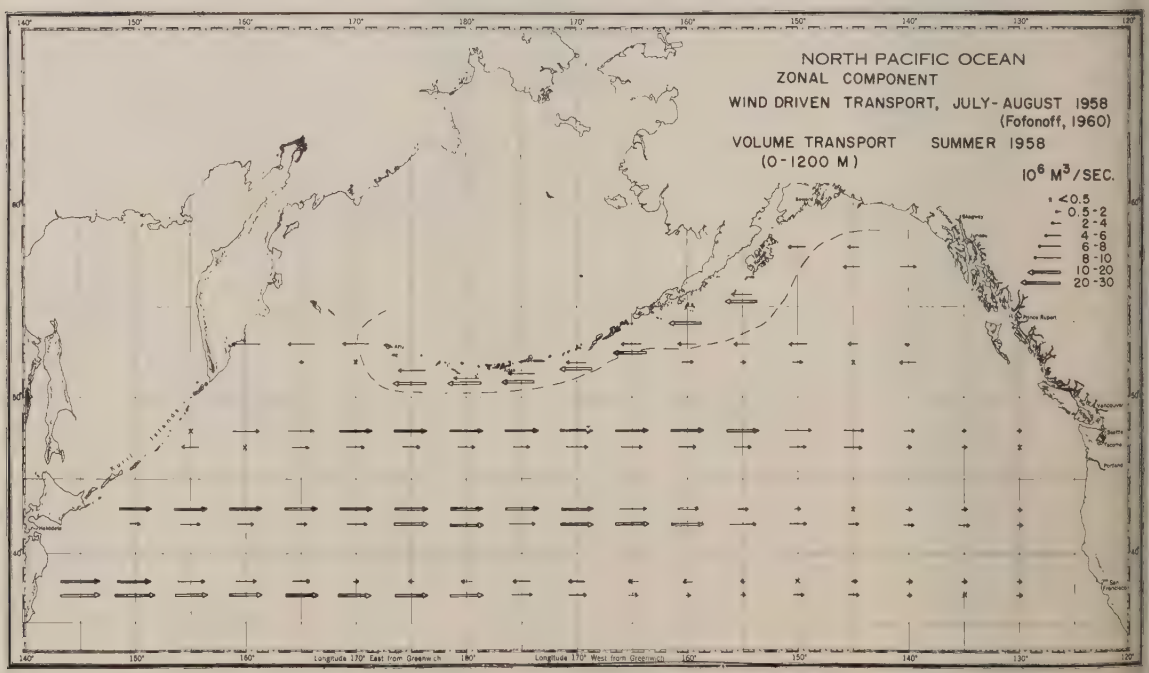


FIGURE 22. Comparison of zonal components of geostrophic mass transport computed from wind stress (upper arrow in each set) and volume transport computed from hydrographic data from 0 to 1200 meters (lower arrow in each set) during Summer 1958. (Dashed line shows approximate extent of Alaska Boundary Current.)

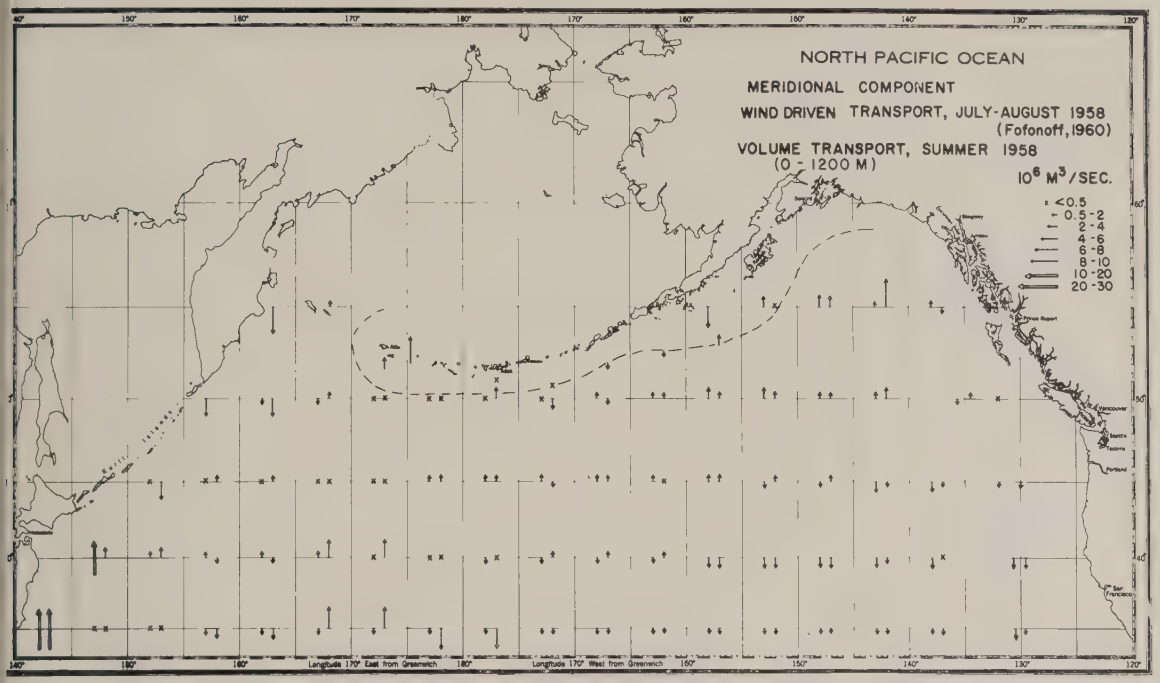


FIGURE 23. Comparison of meridional components of geostrophic mass transport computed from wind stress (left arrow in each set) and volume transport computed from hydrographic data from 0 to 1200 meters (right arrow in each set) during Summer 1958. (Dashed line shows approximate extent of Alaska Boundary Current.)

We are presently evaluating a differential refractometer and will also test an inductive salinometer, both of which appear to fulfill our requirements at this time. The differential refractometer provides precision and accuracy comparable with conductivity salinometers presently in use. The sample and reference cells have small volumes, and little maintenance is required for the instrument. The inductive salinometer also is portable, does not require a temperature-controlled bath, and has accuracy of approximately 0.003 parts per thousand.

Biological Oceanography

All plankton data collected prior to 1961 have been placed on IBM cards to permit qualitative and quantitative comparisons between individual years, and to investigate relationships between the plankton captured by net and the contents of red salmon stomachs.

In 1960 and again in 1961, studies on the vertical distribution of plankton have been made at three stations in the Subarctic Region. Results show that maximum concentrations of plankton occur between 30 to 50 meters depth at night and at depths of 150 meters or greater during the day. This places considerable doubt on the generally accepted theory that salmons come to the surface in the evening or morning to feed. Night light studies have shown that squid are abundant at the surface in this Region, but we do not know whether or not they are attracted to the surface by the light. Comparisons of the plankton and the stomach content of salmon caught at these locations, and investigations into relationships between the plankton and the thermocline are being carried out.

References

FAVORITE, FELIX, AND JAMES F. HEBARD. 1960. Oceanography. *In:* Progress report of investigations by the United States during 1960, p. 18–36. Biological Laboratory, (U.S.) Bureau of Commercial Fisheries, Seattle, Washington, October 12, 1960, (INPFC Doc. 420).

FAVORITE, FELIX, J. W. SCHANTZ AND C. R. HEBARD. 1961. Oceanographic observations, Bristol Bay and Bering Sea 1939–1941 (USCGT *Redwing*). *U.S. Fish and Wildife Service, Special Scientific Report-Fisheries*, No. 381, 323 pp.

FOFONOFF, N. P. 1960. Transport computations for the North Pacific Ocean, 1958. *Fisheries Research Board of Canada, Manuscript Report Series (Oceanographic and Limnological)*, No. 80, 9 p. (Appendix) (also: INPFC Doc. 394).

SALMON SEROLOGY

by George J. Ridgway and Fred M. Utter

Among the methods being applied to the problem of determining the amount of intermingling of Asian and American stocks of salmon in high seas areas are various serological or immunochemical methods. These methods are used to detect characteristic antigenic differences which may occur in different frequencies in genetically isolated populations.

The research which we have conducted includes research on cellular antigens, serum antigens and studies on the use of antigenic and histological changes as indicators of the onset of sexual maturation.

Research on Cellular Antigens

Our studies on the antigens of red blood cells of red, chum, and pink salmon were continued and expanded in the 1961 season. More intensive sampling in the Bristol Bay area and the use of a much larger number of reagents allowed us to make several important demonstrations of antigenic variations between areas. Samples were also taken and tested aboard the chartered vessel MV *Bertha Ann*, allowing us to demonstrate the feasibility of conducting many of our tests and procedures on the high seas when a vessel with sufficient room is available. In addition to Western Alaska areas, the Fraser, Skagit and Columbia River fisheries were sampled and tested extensively.

The sources of the agglutinins used in these studies were heterimmune sera, normal sera, isoimmune sera and phytoagglutinins from plant extracts. Among the immune antisera tested, eight goat anti-salmon tissue sera, four carp anti-salmon red blood cell sera, seventeen chicken anti-salmon red blood cell sera, four carp anti-red cell sera, and five rainbow trout isoimmune sera demonstrated at least some degree of intra- or inter-specific differentiation. Ten rabbit anti-salmon tissue sera and a number of other sera of diverse origin did not detect differences.

The phytoagglutinins used included over thirty-five extracts, many of which reacted strongly. Extensive testing under controlled conditions tended to place in doubt interpretations of observable differences using several of the extracts—principally extracts of baby lima bean—as the results were often not repeatable and appeared to vary with age of cell samples. Several extracts appear to show antigenic variation of a consistent nature, including *Wistaria floribunda* bark, red kidney bean, and *Cytisus scoparius* bark. *Cytisus* appears the most promising at present and has been tested against cells from various areas with good demonstration of variability between populations of red salmon (see Table 10).

Table 10. The relative numbers of red salmon from several areas giving different reactions with *Cytisus scoparius* bark extract.

River	Agglutination score 0	0.5–2	2–5+	Total number tested	Mean score
Branch River	2	34	11	47	1.86
Kenai River	8	12	0	20	0.675
Karluk River	0	14	11	25	2.60
Fraser River	24	7	1	32	0.453
Columbia River	5	3	2	10	1.05

Normal sera from many species of land animals and fishes have been extensively tested. One hundred and ten different land animal sera were provided and tested by Dr. C. Stormont. These include sera from a wide variety of species obtained at the San Diego Zoo and numerous sera from domestic animals. In addition, twenty-five normal horse sera, sixteen normal rabbit sera, English sole sera, crayfish sera, and others have been extensively tested. In general, these tend to demonstrate strong inter-specific antigenic differentiation, but intraspecies differences to a lesser extent.

Isoimmune antisera testing has been limited to sera from rainbow trout. Five have shown clear intraspecific differentiation in red salmon and marked differences between populations even within Bristol Bay (Table 11). Several have also demonstrated intraspecific antigenic variability in pink and chum salmon. We consider this the most important advance made so far in our work, since isoimmune sera are known to detect far greater numbers and finer antigenic differences than other sources of blood typing reagents. In addition, these sera show the most striking and consistent differences of any of the reagents we have so far tested. Some of the properties of these sera and the methods used in their preparation were described in a paper presented to the New York Academy of Sciences at a symposium on "Blood Groups in Infra-human Species".

SALMON DISTRIBUTION AND ABUNDANCE ON THE HIGH SEAS

by Robert French

is marks the seventh year that United States ered research vessels have gillnetted salmon on high seas to determine their distribution and dance. The primary objectives of the fishing es in 1961 were to increase our information of on distribution and abundance and to collect e fish and blood samples for racial studies. ifically, efforts were made to collect samples from rea of the Japanese mothership salmon fishery in May and June and to gain information on the abundance of the current Bristol Bay red salmon run in the eastern Bering Sea during the month of June. Fishing was continued south of the Aleutian Islands during July and August to obtain an index of the abundance of immature red salmon. In addition, fishing cruises in the Gulf of Alaska increased our knowledge of salmon found in that area. The stations fished in 1961 are shown in Figure 9.

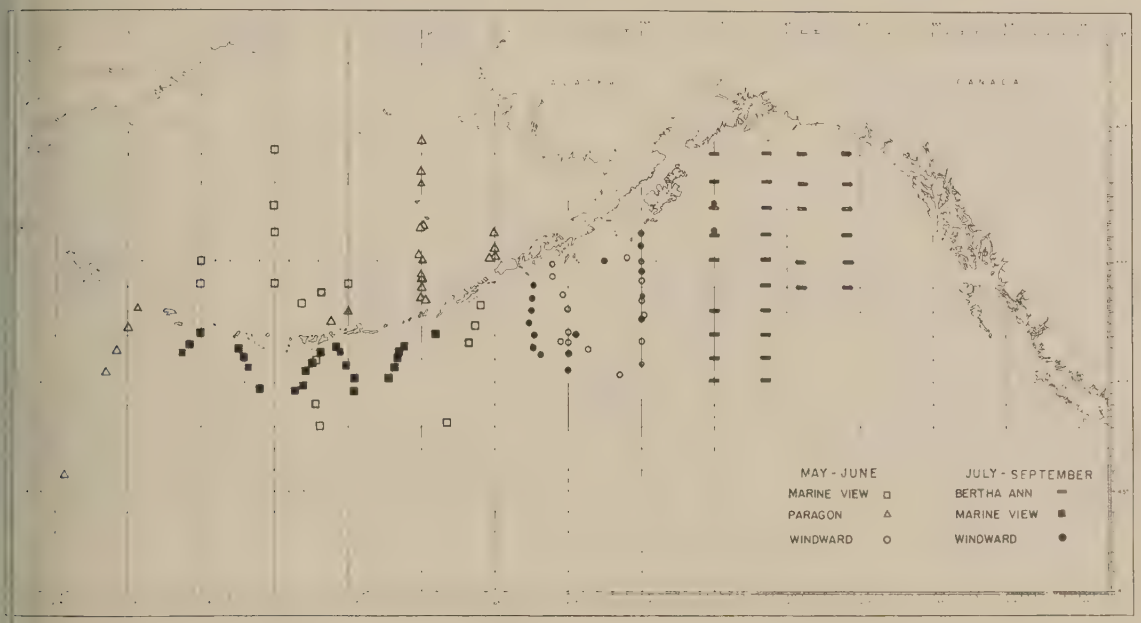


FIGURE 9. Fishing stations of United States research vessels in 1961.

our gillnet fishing vessels were chartered for the l season. These were the schooner *Paragon*, seiners *Marine View* and *Windward*, and the *Bertha* , a converted Army refrigerated cargo vessel.

The fishing effort per vessel in 1961 was similar hat of 1959 and 1960 with the exception that four ditional shackles of net ($3\frac{7}{8}$-inch mesh) were led to the 36 shackles used the previous two years. e standard for all four vessels in 1961 was thus 40 ckles of net (2,000 fathoms) made up of 24 shackles $4\frac{1}{2}$-inch mesh and four shackles each of $5\frac{1}{4}$, $3\frac{7}{8}$, and $2\frac{1}{2}$-inch mesh. The $3\frac{7}{8}$-inch mesh was d in order to fish a more even distribution of mesh sizes thus filling the $1\frac{1}{4}$-inch gap between the $3\frac{1}{4}$ and $4\frac{1}{2}$-inch mesh.

CATCH DATA

The main feature of the 1961 fishing cruises was the reduced catches of red, chum, and pink salmon. Table 9 lists the catches of the four vessels by individual sets and mesh sizes. For ease of comparisons with other years, catches in the Aleutian area and in the Gulf of Alaska will be reported separately. As in past years we have designated May and June as the spring season and July-September as the summer season.

nternational North Pacific Fisheries Commission, Annual Report 1961,
'ancouver, Canada, 1963, p. 92-101.

TABLE 7. Recoveries of coho salmon tagged in the Gulf of Alaska in 1961 (tags received through January 1, 1962).

Recovery area	Area of release (see Fig. 1)						TOTAL
	W5058	W5056	W5054	W4558	W4056	W2548	
Copper River	1	1		1			3
Copper River to Cape Spencer			1	2			3
S.E. Alaska north of 56°					1		1
S.E. Alaska south of 56°				3			3
Washington Coast						1	1
Fraser River						3	3
Puget Sound						3	3
TOTAL	1	1	1	6	1	7	17

TABLE 8. Recoveries of king salmon tagged in the Gulf of Alaska in 1961 (tags received through January 1, 1962).

Recovery area	Area of release (see Fig. 1)			TOTAL
	W4558	W4058	W2548	
Copper River to Cape Spencer		1		1
S.E. Alaska north of 56°	2	3		5
West Coast of Vancouver I.			2	2
Strait of Juan de Fuca			5	5
Fraser River			1	1
TOTAL	2	4	8	14

kings tagged were small immature fish, but large enough that returns in 1962 and 1963 should be substantial.

A single steelhead was returned from the 15 tagged. It was released near Baranof Island off Southeast Alaska and recovered in Queen Charlotte Sound. Maturity of the steelhead tagged has not been determined.

Note: Since submission of the above report on U. S. high seas tagging for 1961, an additional 26 tags were received from the U.S.S.R. Table A summarizes these returns by species, year, and area. The return of red salmon returned is of particular interest. It was tagged as a 2-winter age immature fish south of Attu on July 9, 1960, and recovered July 25, 1961, in the Kamchatka River estuary. This is the eastern most tagging to date that has yielded a red salmon return from the Asian coast.

TABLE A. Release and recovery data for 26 U.S. tags returned by the U.S.S.R. in March, 1962.

No. of recovered fish	Species	Year tagged	Year recovered	Area of tagging	Recovery location
1	Red	1960	1961	8050	Kamchatka River
1	Chum	1961	1961	8050	W. Kamchatka
1	Chum	1961	1961	8050	E. Kamchatka
4	Chum	1961	1961	8050	Sakhalin Island
2	Chum	1961	1961	W7052	E. Kamchatka
3	Chum	1961	1961	W7052	Anadyr River
1	Chum	1960	1961	8050	Okhotsk Coast
1	Chum	1960	1961	W7052	Okhotsk Coast
1	Chum	1959	1961	E 7052	Okhotsk Coast
1	Chum	1959	1961	E 7052	Sakhalin Island
6	Pink	1961	1961	8050	Karaginsky area
3	Pink	1961	1961	W7052	Karaginsky area
1	Pink	1961	1961	W7052	U.S.S.R. unknown

(In addition one pink salmon tagged by the U.S. Bureau of Commercial Fisheries south of Unimak Island was recovered on East Kamchatka).

Aleutian Area. Red salmon catches in the Aleutian area were much smaller than the catches obtained in 1959 and 1960[1]. While the fishing effort (number of shackles fished) averaged about 90 percent of that for 1959–60, total catches in 1961 were only 52 and 47 percent respectively of those for the two previous years. This was mainly because fewer immature fish were present in 1961. In the area south of the Aleutian Islands catches of immature red salmon during the summer season averaged about 1.6 fish per shackle compared to an average of about five fish per shackle in 1959–60. The catch per shackle of juvenile red salmon which had spent one year at sea was 1.7 fish; the catch was about 1.5 fish per shackle for immature fish which had spent two years at sea. These are the two age groups which after one and three years at sea will provide the bulk of the Bristol Bay red salmon runs in 1962.

Total chum salmon catches in the Aleutian area were about one-third of those in 1959 and 1960. The fishing effort was approximately the same in all three years. The catch per unit of effort of the juvenile chums (2-year-old fish) was about 45 percent of that obtained in 1959 and 1960; for the older chum salmon (3, 4, 5, and 6-year-old fish) the catch per unit of effort was about 34 percent of that obtained the two previous years.

Pink salmon catches were much lower than expected. In recent years in high seas areas pink salmon catches in odd numbered years greatly surpassed catches in even numbered years. The catch in 1961 was comparable to that in 1960 and far below 1959 catches.

Among species of less importance in the Aleutian areas (silver and king salmon and steelhead trout) the catch of silver salmon showed a marked increase over catches in past years. The 662 silvers caught were far more than have been taken in any other year. Sixty-four percent of the silver salmon catch in 1961 was taken in two sets south of the Aleutian Islands during the summer season. These two sets were at 51°31′N. latitude, and 177°46′E. longitude on July 26 and at 51°12′N. latitude and 173°58′E. longitude on July 30.

The king salmon catch of 48 fish in 1961 was similar to the 54 taken in 1960, but was about one-half of the total caught in 1959.

[1] High seas catch data are given in the Annual Report of the International North Pacific Fisheries Commission for 1959 and for 1960.

Steelhead trout catches in the Aleutian Islands area were reduced from those of the two previous seasons. The total of 33 steelhead was a little over half the number caught in 1959 and in 1960.

Gulf of Alaska. Catch data for the Gulf of Alaska are shown in the catch tables for the *Windward* and *Bertha Ann.* (See Table 9.) Of the red salmon catch of 2,093 fish in the western Gulf made by the *Windward*, 970 reds or 46 percent of the total were taken in one set on June 8 at 53°40′N. latitude and 160°24′W. longitude. In size and age composition these red salmon were similar to the 1961 adult run to Bristol Bay.

As shown in the table, chum salmon predominated in the catches during the summer season in the central and western Gulf of Alaska.

Catch by mesh size. The greatest number of salmon were taken in the $4\frac{1}{2}$-inch mesh. This was to be expected since each string of gear is composed of 24 shackles of $4\frac{1}{2}$-inch mesh and four each of the other sizes. Ranking the catches of the five mesh sizes by season (species combined) according to the number of fish caught per shackle, we have the following array: $4\frac{1}{2}$, $5\frac{1}{4}$, $3\frac{7}{8}$, $3\frac{1}{4}$, and $2\frac{1}{2}$-inch mesh in the spring season, and $3\frac{7}{8}$, $4\frac{1}{2}$, $3\frac{1}{4}$, $5\frac{1}{4}$, and $2\frac{1}{2}$-inch mesh in the summer.

Distribution and Relative Abundance

The distribution and relative abundance of the 1961 high seas salmon catches as measured by gillnets are illustrated in Figures 10 to 18. Because age determinations by scale readings have not been completed, we have estimated the abundance of juvenile and older aged fish from the numbers taken in the different mesh sizes. The smaller mesh sizes ($2\frac{1}{2}$ and $3\frac{1}{4}$-inch) usually catch red salmon which have spent one winter at sea and 2-year-old chum salmon. The larger mesh sizes ($3\frac{7}{8}$, $4\frac{1}{2}$, and $5\frac{1}{4}$-inch) usually take only red salmon which have spent two, three, or four winters at sea; 3, 4, 5, and 6-year-old chum salmon; and mature pink salmon.

Figures 10 to 15 show the relative abundance of the older age groups in the catches for both the spring and summer seasons. Relatively few large catches of red salmon were made at the stations fished this year. As previously stated, the total catch was lower than those of 1959 and 1960. Our catches in the Gulf of Alaska did not indicate dense concentrations of red salmon in the station pattern fished this year.

TABLE 9. Salmon catch by United States MV *Bertha Ann* August 12–September 29, 1961.

Set no.	Date	Position		Surf. temp. °C.	Number of shackles	Red Mesh size					Total
		Latitude	Longitude			$5\frac{1}{4}$	$4\frac{1}{2}$	$3\frac{7}{8}$	$3\frac{1}{4}$	$2\frac{1}{2}$	
1	8/12	58°00′N.	150°00′W.	11.2	38	0	0	0	0	0	0
2	8/13	59°06′N.	149°52′W.	12.6	38	0	4	2	0	0	6
3	8/17	56°59′N.	150°07′W.	13.6	38	0	3	1	0	1	5
4	8/19	55°58′N.	150°01′W.	13.6	38	0	3	3	1	0	7
5	8/20	54°56′N.	150°00′W.	12.4	38	0	3	1	1	0	5
6	8/21	52°59′N.	150°02′W.	12.8	38	5	15	4	0	0	24
7	8/22	52°00′N.	150°00′W.	12.9	38	3	34	9	0	0	46
8	8/23	51°01′N.	149°56′W.	12.8	38	0	12	4	0	0	16
9	8/24	50°00′N.	150°02′W.	12.9	35	0	0	0	0	0	0
10	8/25	50°00′N.	147°00′W.	13.3	35	0	0	0	0	0	0
11	8/26	51°00′N.	147°00′W.	13.2	35	0	0	0	0	0	0
12	8/27	52°00′N.	147°00′W.	13.3	35	1	3	0	0	0	4
13	8/29	53°00′N.	147°00′W.	13.2	35	0	5	1	0	0	6
14	8/30	54°00′N.	147°00′W.	12.8	35	0	10	1	0	0	11
15	8/31	55°00′N.	147°00′W.	13.4	35	1	14	3	0	0	18
16	9/1	56°00′N.	147°00′W.	13.3	35	0	10	0	0	0	10
17	9/2	57°00′N.	147°00′W.	13.2	35	0	1	0	0	0	1
18	9/3	58°00′N.	147°00′W.	13.6	35	1	0	1	1	0	3
19	9/4	59°00′N.	147°00′W.	13.8	35	0	0	0	0	0	0
20	9/10	59°00′N.	144°00′W.	13.1	12	0	0	0	0	0	0
21	9/14	57°59′N.	144°04′W.	13.0	34	0	1	0	0	0	1
22	9/15	57°00′N.	144°00′W.	12.6	34	0	0	0	0	0	0
23	9/17	55°00′N.	144°00′W.	12.8	34	0	0	0	0	0	0
24	9/20	54°00′N.	144°00′W.	12.1	34	0	0	2	0	0	2
25	9/21	54°00′N.	141°00′W.	12.8	38	0	1	0	0	0	1
26	9/22	55°00′N.	141°00′W.	12.4	40	0	0	0	0	0	0
27	9/23	56°00′N.	141°00′W.	12.6	40	0	2	0	0	0	2
28	9/26	57°00′N.	141°00′W.	12.2	39	1	0	0	0	0	1
29	9/27	58°00′N.	141°00′W.	12.2	40	0	0	0	0	0	0
30	9/29	59°00′N.	141°00′W.	11.7	40	0	0	0	0	0	0
TOTAL					1074	12	121	32	3	1	169

Sets 7 and 8—nine nets rolled. Sets 9, 10, and 11—one net rolled. Set 20—lost 28 nets.
Set 27—four nets rolled. Set 29—nine nets rolled. Set 30—lost 39 nets.

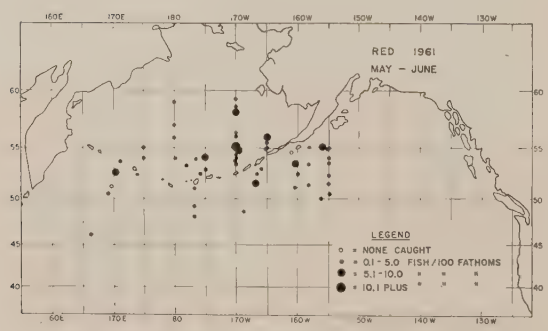


FIGURE 10. Red salmon relative abundance, May and June 1961—2, 3, 4 winters-in-the-sea fish taken in 3-7/8, 4-1/2, 5-1/4-inch mesh nets.

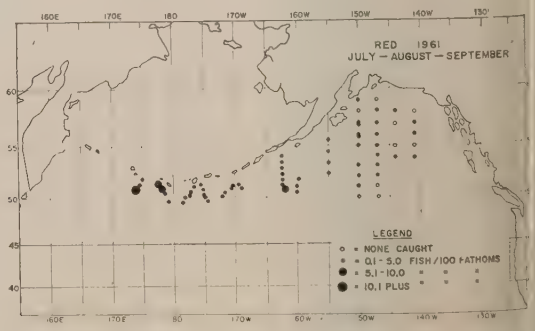


FIGURE 11. Red salmon relative abundance, July, August and September 1961—2, 3, 4 winters-in-the-sea fish taken in 3-7/8, 4-1/2, 5-1/4-inch mesh nets.

tates research vessels in 1961.

Chum						Pink									
Mesh size						Mesh size									
5¼	4½	3⅞	3¼	2½	Total	5¼	4½	3⅞	3¼	2½	Total	Silver	King	Total salmon catch	Steel-head
0	0	0	0	0	0	4	7	0	0	0	11	5	0	16	0
0	0	0	0	0	0	10	7	1	0	0	18	22	0	46	0
3	41	30	13	0	87	1	1	0	0	0	2	6	1	101	5
11	143	60	33	0	247	0	2	0	0	0	2	4	0	260	5
7	80	9	0	0	96	0	1	0	0	0	1	0	0	102	0
2	5	2	0	0	9	0	0	0	0	0	0	0	0	33	0
2	9	11	7	0	29	0	0	0	0	0	0	0	0	75	3
0	7	0	0	0	7	0	0	0	0	0	0	0	0	23	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	13	15	5	0	33	0	0	0	0	0	0	1	0	38	0
0	16	6	1	0	23	0	0	0	0	0	0	0	0	29	2
9	15	1	3	0	28	0	0	0	0	0	0	0	0	39	2
7	131	92	33	2	265	0	0	0	0	0	0	0	0	283	3
3	26	14	0	0	43	0	0	0	0	0	0	2	0	55	1
0	16	3	0	0	19	0	0	0	0	0	0	0	0	20	0
2	12	4	0	0	18	0	3	1	0	0	4	3	0	28	0
0	6	0	1	0	7	0	0	0	0	0	0	2	0	9	1
1	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
3	19	8	11	0	41	0	0	0	0	0	0	0	0	42	1
9	60	14	5	0	88	0	0	0	0	0	0	0	0	88	1
3	8	1	0	0	12	0	0	0	0	0	0	0	0	12	0
2	1	1	0	0	4	0	0	0	0	0	0	0	0	6	3
1	3	1	0	0	5	0	0	0	0	0	0	0	0	6	1
1	2	0	0	0	3	0	0	0	0	0	0	0	0	3	0
0	2	0	0	0	2	0	0	0	0	0	0	0	0	4	0
4	3	0	0	0	7	0	0	0	0	0	0	0	0	8	1
2	4	0	1	0	7	0	0	0	0	0	0	1	0	8	3
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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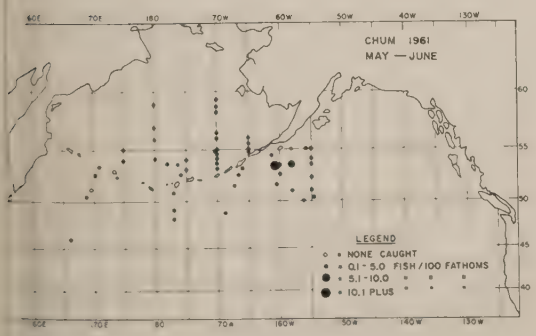


IGURE 12. Chum salmon relative abundance, May and June, 1961—3, 4, 5, 6-year-old fish taken in 3-7/8, 4-1/2, and 5-1/4-inch mesh nets.

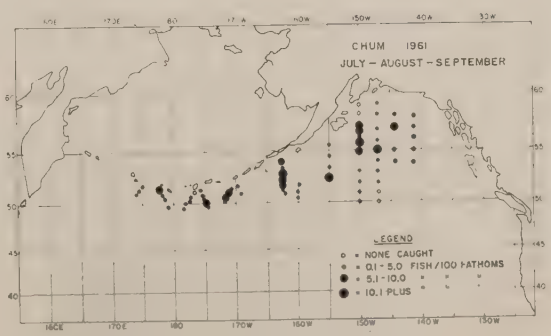


FIGURE 13. Chum salmon relative abundance, July, August, and September 1961—3, 4, 5, 6-year-old fish taken in 3-7/8, 4-1/2, and 5-1/4-inch mesh nets.

TABLE 9. Continued.

MV *Windward* June 5–September 3, 1961.

Set no.	Date	Position		Surf. temp. °C.	Number of shackles	Red Mesh size					TOTAL
		Latitude	Longitude			5¼	4½	3⅞	3½	2½	
1	6/5	51°47′N.	160°30′W.	6.3	40	9	20	0	0	0	29
2	6/8	53°40′N.	160°24′W.	7.2	40	163	758	18	17	14	970
3	6/10	54°20′N.	161°00′W.	7.0	40	0	0	0	0	0	0
4	6/14	54°52′N.	158°00′W.	8.5	40	0	5	1	0	0	6
5	6/15	55°03′N.	156°00′W.	10.0	40	10	73	0	0	0	83
6	6/16	54°58′N.	155°06′W.	10.3	40	3	24	0	0	0	27
7	6/17	54°05′N.	155°00′W.	9.8	40	0	16	0	0	0	16
8	6/18	53°25′N.	155°00′W.	10.0	40	1	13	0	0	0	14
9	6/19	52°43′N.	154°53′W.	9.5	40	3	18	0	0	0	21
10	6/20	51°45′N.	155°07′W.	8.7	40	3	82	22	10	6	123
11	6/21	50°47′N.	155°07′W.	8.9	40	1	18	12	1	3	35
12	6/22	50°17′N.	156°30′W.	8.7	40	1	9	3	0	0	13
13	6/25	51°22′N.	158°45′W.	9.1	40	3	12	0	1	0	16
14	6/27	51°46′N.	160°05′W.	8.7	40	0	11	1	1	2	15
15	6/28	52°20′N.	160°06′W.	10.2	40	2	18	1	4	5	30
16	6/29	53°11′N.	160°12′W.	9.8	40	0	13	0	0	2	15
17	7/9	54°00′N.	162°30′W.	9.8	40	12	27	8	0	0	47
18	7/10	53°30′N.	162°30′W.	10.8	40	3	17	3	8	4	35
19	7/11	53°00′N.	162°30′W.	11.3	40	2	25	10	11	9	57
20	7/12	52°30′N.	162°38′W.	11.5	40	5	44	18	17	4	88
21	7/13	52°00′N.	162°20′W.	10.5	40	3	46	19	19	3	90
22	7/14	51°30′N.	162°30′W.	10.5	40	0	31	6	4	0	41
23	7/17	51°09′N.	162°07′W.	10.4	40	2	83	24	15	1	125
24	7/25	50°30′N.	160°00′W.	10.8	40	0	42	14	5	0	61
25	7/26	51°15′N.	160°00′W.	11.3	40	4	49	8	5	0	66
26	7/27	52°03′N.	159°44′W.	11.3	40	1	13	3	5	0	22
27	8/7	55°00′N.	157°30′W.	12.1	12	0	1	0	0	0	1
28	8/14	56°00′N.	155°00′W.	10.1	40	0	0	0	0	0	0
29	8/17	55°30′N.	155°00′W.	13.4	33	0	3	0	1	0	4
30	8/21	54°30′N.	155°04′W.	12.8	29	1	10	3	3	0	17
31	8/22	53°30′N.	155°00′W.	12.8	29	0	13	1	0	0	14
32	8/23	52°30′N.	155°00′W.	12.2	29	0	3	0	0	0	3
33	9/2	57°00′N.	150°00′W.	13.3	37	0	8	0	0	0	8
34	9/3	56°05′N.	150°00′W.	12.2	37	0	1	0	0	0	1
TOTAL					1286	232	1506	175	127	53	2093

Set 7—eight nets rolled. Set 14—two nets rolled. Set 27—twenty-eight nets rolled.
Set 28—forty nets rolled. Set 29—three nets rolled. Set 34—twenty nets rolled.
Set 17—nets in water 64 hours due to rough seas.

Chum salmon were taken at nearly every station fished during the spring season. However, dense concentrations of the older chum salmon were not encountered. In the summer season the older chums appeared to be more abundant in parts of the Gulf of Alaska than in the central Aleutians area.

Figures 14 and 15 illustrate the relative abundance of pink salmon for 1961. This year there was only one instance where the catch was more than 10 fish per 100 fathoms of net.

The distribution and relative abundance of juveni red and chum salmon caught in the 2½ and 3¼-in mesh nets are portrayed in Figures 16 to 18. T abundance of juvenile red and chum salmon measured by gillnet catches appeared to be great in the Aleutian area than in the Gulf of Alaska. was interesting to note that, although juvenile r salmon were taken at various stations in the spri

Chum						Pink										
Mesh size						Mesh size										
$5\frac{1}{4}$	$4\frac{1}{2}$	$3\frac{7}{8}$	$3\frac{1}{4}$	$2\frac{1}{2}$	Total	$5\frac{1}{4}$	$4\frac{1}{2}$	$3\frac{7}{8}$	$3\frac{1}{4}$	$2\frac{1}{2}$	Total	Silver	King	Total salmon catch	Steelhead
4	8	0	0	0	12	0	3	0	0	0	3	0	0	44	0
11	188	2	1	0	232	0	6	0	0	0	6	0	0	1208	0
0	3	0	0	0	3	0	0	0	0	0	0	0	0	3	0
1	1	0	0	0	2	0	0	0	0	0	0	0	0	8	0
5	29	1	0	0	35	1	2	0	0	0	3	0	0	121	0
5	39	1	0	0	45	0	5	0	0	0	5	0	0	77	0
4	68	0	0	0	72	1	11	0	0	0	12	0	0	100	0
4	52	1	0	0	67	1	22	1	0	0	24	0	0	105	0
2	51	2	0	0	65	1	35	0	0	0	36	0	0	122	0
8	64	3	0	0	75	0	97	10	2	0	109	0	0	307	4
1	13	2	0	0	16	3	35	8	0	0	46	1	1	99	1
2	30	5	0	0	37	2	54	5	1	0	62	0	0	112	3
2	21	0	0	0	23	0	17	1	0	0	18	0	0	57	1
7	127	2	5	0	141	1	83	3	0	0	87	1	0	244	0
0	39	2	0	0	41	15	127	6	0	0	148	3	0	222	0
0	32	0	0	0	32	0	16	0	0	0	16	1	0	64	0
7	70	13	0	0	110	0	6	0	0	0	6	3	0	166	0
0	51	2	0	0	63	1	12	3	0	0	16	2	1	117	0
8	168	18	9	3	226	10	63	5	2	0	80	2	0	365	3
4	130	8	6	0	158	6	76	1	0	0	83	5	1	335	0
3	83	4	2	1	93	2	32	3	0	0	37	1	1	222	0
0	19	13	1	0	33	1	12	0	0	0	13	1	0	88	1
1	40	2	1	0	44	1	8	0	0	0	9	1	1	180	2
3	52	7	12	1	75	1	1	0	0	0	2	5	3	146	3
3	22	5	1	0	31	0	14	0	0	0	14	3	1	115	8
4	14	3	2	0	23	3	28	2	1	0	34	4	0	83	4
0	2	0	0	0	2	0	2	0	0	0	2	0	0	5	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	14	1	0	0	28	2	6	0	0	0	8	2	0	42	3
0	24	4	1	0	29	0	1	0	0	0	1	0	0	47	8
0	20	3	2	0	25	0	1	0	0	0	1	0	0	40	13
9	111	9	2	0	131	2	0	0	0	0	2	0	0	136	4
3	62	7	7	1	80	1	0	0	0	0	1	4	0	93	1
0	9	0	0	0	9	0	0	0	0	0	0	0	0	10	2
4	1656	120	52	6	2058	55	775	48	6	0	884	39	9	5083	61

son, only one juvenile chum was caught (figure shown).

Salmon Migration

report on the direction of movement of high seas on stocks for 1959 and 1960, as determined from il et catches, is being prepared for publication.

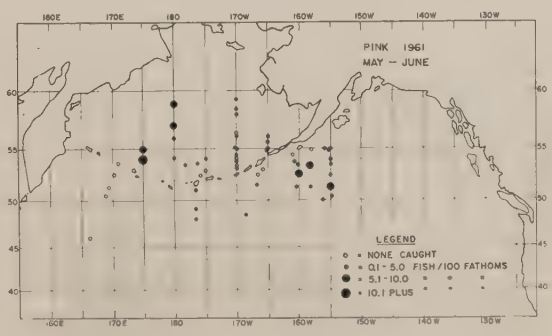


Figure 14. Pink salmon relative abundance, May and June 1961.

TABLE 9. Continue

MV *Marine View* May 5–August 17, 1961.

Set no.	Date	Position		Surf. temp. °C.	Number of shackles	Red Mesh size					Tota
		Latitude	Longitude			5¼	4½	3⅞	3¼	2½	
1	5/5	55°00′N.	155°00′W.	5.7	40	7	38	1	1	0	47
2	5/14	53°12′N.	165°52′W.	5.3	40	0	14	0	0	0	14
3	5/15	52°26′N.	166°28′W.	5.4	40	12	64	3	0	0	79
4	5/16	51°38′N.	166°48′W.	5.4	40	13	94	2	2	0	111
5	5/21	48°15′N.	168°15′W.	5.9	40	5	24	1	0	0	30
6	5/29	50°57′N.	166°02′W.	4.9	40	7	17	1	2	0	27
7	6/2	49°04′N.	177°03′W.	4.9	40	2	16	0	2	0	20
8	6/3	48°00′N.	176°54′W.	4.5	40	0	6	0	0	0	6
9	6/13	54°00′N.	175°00′W.	5.8	40	10	100	4	1	1	116
10	6/18	53°46′N.	176°37′W.	6.3	40	6	62	5	2	2	77
11	6/19	53°15′N.	178°06′W.	6.2	40	14	54	7	1	0	76
12	6/20	54°00′N.	179°46′W.	5.8	40	5	26	1	0	0	32
13	6/21	56°00′N.	180°	5.3	40	10	41	3	1	0	55
14	6/23	57°00′N.	180°	5.3	40	2	26	1	1	2	32
15	6/25	59°00′N.	180°	4.5	40	6	35	2	0	1	44
16	6/27	55°00′N.	175°00′E.	5.6	40	1	31	2	0	4	38
17	6/28	54°00′N.	175°00′E.	5.9	40	2	27	2	3	1	35
18	7/10	51°18′N.	176°50′W.	8.4	40	0	1	0	0	0	1
19	7/11	50°51′N.	177°18′W.	7.6	40	3	13	5	1	0	22
20	7/12	50°25′N.	177°43′W.	8.0	40	0	19	1	0	0	20
21	7/13	49°57′N.	178°09′W.	7.5	40	0	3	0	0	0	3
22	7/14	49°30′N.	178°34′W.	8.0	40	1	8	0	1	0	10
23	7/15	49°42′N.	179°06′E.	7.5	40	0	7	2	0	0	9
24	7/24	50°35′N.	178°23′E.	7.6	40	1	49	2	3	0	55
25	7/25	51°03′N.	178°04′E.	8.0	40	5	70	36	42	4	157
26	7/26	51°31′N.	177°46′E.	8.8	40	2	120	34	42	9	207
27	7/27	52°00′N.	175°00′E.	8.0	40	0	39	4	3	2	48
28	7/29	51°35′N.	174°27′E.	7.8	40	2	51	27	22	5	107
29	7/30	51°12′N.	173°58′E.	8.0	40	9	187	32	46	4	278
30	8/4	51°30′N.	175°45′W.	9.2	40	1	3	0	1	0	5
31	8/5	51°02′N.	175°27′W.	10.2	40	4	43	16	8	1	72
32	8/6	50°35′N.	175°10′W.	10.0	40	3	30	2	10	0	45
33	8/7	50°07′N.	174°51′W.	9.5	40	2	67	8	10	0	87
34	8/8	49°28′N.	174°35′W.	9.5	40	1	43	8	5	0	57
35	8/10	50°08′N.	172°10′W.	9.8	40	5	19	2	3	0	29
36	8/11	50°35′N.	171°54′W.	10.1	40	4	54	8	10	1	77
37	8/12	51°02′N.	171°37′W.	10.1	40	4	49	8	23	1	85
38	8/13	51°30′N.	171°20′W.	8.7	40	3	8	1	6	3	21
39	8/16	52°02′N.	169°17′W.	10.7	40	0	5	0	4	1	10
40	8/17	51°20′N.	168°30′W.	10.8	40	2	13	7	21	1	44
TOTAL					1600	154	1576	238	277	43	2288

Set 12—one net rolled. Set 33—two nets rolled. Set 38—four nets partially rolled.

Chum						Pink									
Mesh size						Mesh size									
5¼	4½	3⅞	3¼	2½	Total	5¼	4½	3⅞	3¼	2½	Total	Silver	King	Total salmon catch	Steel-head
4	16	1	0	0	21	0	0	0	0	0	0	0	0	68	0
0	3	0	0	0	3	0	0	0	0	0	0	0	0	17	0
1	7	0	0	0	8	0	0	0	0	0	0	0	0	87	0
12	56	0	1	0	69	0	2	0	0	0	2	0	0	182	0
10	41	0	0	0	51	0	4	0	0	0	4	0	1	86	0
1	13	0	1	0	15	0	1	0	0	0	1	0	0	43	0
5	29	6	0	0	40	1	14	0	2	1	18	0	0	78	0
0	32	4	0	0	36	0	12	6	0	0	18	0	0	60	0
1	7	0	0	0	8	0	8	1	0	0	9	0	7	140	0
2	23	1	0	0	26	1	55	6	0	0	62	0	0	165	0
0	7	0	0	0	7	0	16	1	0	0	17	0	0	100	0
0	1	0	0	0	1	1	4	0	0	0	5	0	0	38	0
3	7	0	0	0	10	2	34	4	1	0	41	0	5	111	0
2	7	0	0	0	9	7	74	8	1	0	90	0	6	137	0
2	11	0	0	0	13	9	93	7	0	0	109	0	2	168	0
3	13	1	0	0	17	6	104	1	0	0	111	0	2	168	0
2	41	7	14	1	65	3	165	19	5	0	192	0	0	292	0
0	0	0	0	0	0	0	1	0	0	0	1	0	0	2	0
0	4	1	3	38	46	1	20	1	0	0	22	0	0	90	0
0	12	2	1	2	17	0	32	3	0	0	35	2	0	74	0
0	16	3	4	1	24	0	7	1	0	0	8	2	0	37	0
0	0	1	4	6	11	0	10	0	0	0	10	1	0	32	0
0	4	1	6	5	16	1	3	0	0	0	4	7	0	36	0
1	33	6	18	6	64	0	1	0	0	0	1	45	1	166	2
4	38	9	8	5	64	1	7	1	0	0	9	71	2	303	0
1	89	14	11	20	135	0	24	2	1	1	28	225	2	597	0
1	20	3	28	29	81	0	7	0	0	0	7	7	0	143	0
3	15	0	4	5	27	0	7	2	0	0	9	51	4	198	0
6	31	3	16	8	64	0	6	1	1	0	8	205	0	555	0
1	46	10	6	1	64	0	4	0	0	0	4	7	1	81	0
1	40	3	4	0	48	0	1	0	0	0	1	12	0	133	1
2	48	10	3	0	63	1	0	0	0	0	1	1	1	111	2
1	115	35	3	0	154	0	0	0	0	0	0	8	1	250	5
2	48	7	2	0	59	0	0	0	0	0	0	2	0	118	2
1	36	12	1	0	50	0	0	1	0	0	1	3	2	85	3
4	67	14	2	0	87	0	1	0	0	0	1	2	0	167	1
6	83	19	4	0	112	0	0	0	0	0	0	2	0	199	10
5	61	6	4	0	76	1	2	1	0	0	4	7	0	108	5
7	59	2	3	0	71	0	0	0	0	0	0	1	0	82	0
1	12	2	2	0	17	0	0	0	0	0	0	1	0	62	2
95	1191	183	153	127	1749	35	719	66	11	2	833	662	37	5569	33

TABLE 9. Continued.

MV *Paragon* May 20–June 30, 1961.

Set no.	Date	Position: Latitude	Position: Longitude	Surf. temp. °C.	Number of shackles	Red Mesh size: 5¼	4½	3⅞	3¼	2½	TOTAL
1	5/20	46°00′N.	166°00′E.	3.1	40	0	5	0	0	0	5
2	5/29	53°21′N.	170°53′E.	4.0	40	10	13	0	0	0	23
3	5/30	52°25′N.	170°14′E.	4.4	40	23	79	10	5	0	117
4	6/1	51°30′N.	169°31′E.	4.1	40	0	0	0	0	0	0
5	6/2	50°35′N.	168°57′E.	4.1	40	4	15	0	0	0	19
6	6/9	52°30′N.	176°00′W.	5.3	40	1	14	1	0	0	16
7	6/10	53°02′N.	175°00′W.	5.3	40	6	14	0	1	1	22
8	6/12	53°25′N.	170°00′W.	6.0	40	3	55	4	3	0	65
9	6/13	54°16′N.	170°00′W.	7.1	40	4	25	0	1	0	30
10	6/14	55°09′N.	170°00′W.	8.3	40	12	212	17	11	2	254
11	6/16	56°11′N.	170°00′W.	6.8	40	8	56	3	1	1	69
12	6/17	57°48′N.	169°58′W.	5.2	40	14	115	9	0	1	139
13	6/18	59°14′N.	169°58′W.	3.7	40	5	8	1	2	0	16
14	6/19	58°20′N.	170°00′W.	4.7	40	6	41	2	1	0	50
15	6/21	56°14′N.	169°58′W.	6.9	40	4	24	1	2	1	32
16	6/22	55°05′N.	170°03′W.	7.0	40	9	131	5	1	0	146
17	6/23	54°27′N.	170°00′W.	7.6	40	2	36	2	2	0	42
18	6/24	53°56′N.	170°01′W.	7.2	40	2	36	12	2	0	52
19	6/25	53°26′N.	169°57′W.	7.1	39	14	41	11	2	3	71
20	6/27	55°00′N.	165°02′W.	7.5	39	0	1	0	0	0	1
21	6/28	55°23′N.	164°58′W.	7.0	39	1	2	0	0	0	3
22	6/29	55°59′N.	165°00′W.	7.2	39	16	134	3	1	0	154
23	6/30	54°59′N.	165°06′W.	6.9	39	6	27	3	0	0	36
TOTAL					915	150	1084	84	35	9	1362
Gulf of Alaska—*Bertha Ann*					1074	12	121	32	3	1	169
Windward					1286	232	1506	175	127	53	2093
TOTAL					2360	244	1627	207	130	54	2262
Aleutian Area—*Marine View*					1600	154	1576	238	277	43	2288
Paragon					915	150	1084	84	35	9	1362
TOTAL					2515	304	2660	322	312	52	3650
GRAND TOTAL					4875	548	4287	529	442	106	5912

Set 1—forty nets rolled. Set 23—nets partially rolled.
Sets 19–23—one shackle of 3⅞-inch mesh not fished.

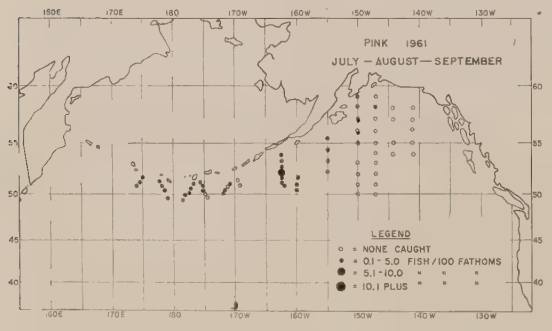


FIGURE 15. Pink salmon relative abundance, July, August, and September 1961.

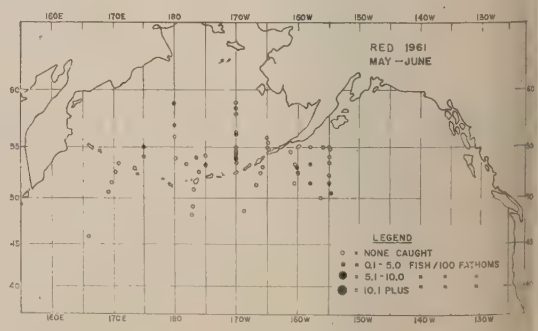
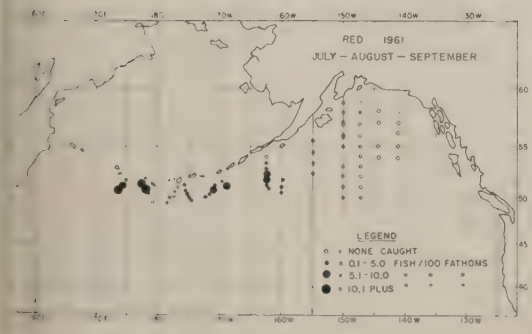


FIGURE 16. Juvenile red salmon relative abundance, May and June 1961—1 winter-in-the-sea fish taken in 2-1/2 and 3-1/4-inch mesh nets.

Chum						Pink										
Mesh size						Mesh size										
5¼	4½	3⅞	3¼	2½	Total	5¼	4½	3⅞	3¼	2½	Total	Silver	King	Total salmon catch	Steel-head
0	2	0	0	0	2	0	0	0	0	0	0	0	0	7	0
5	18	0	0	0	23	0	0	0	0	0	0	0	0	46	0
1	11	0	0	0	12	0	0	0	0	0	0	0	0	129	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	6	0	0	0	6	0	0	0	0	0	0	0	0	25	0
0	1	0	0	0	1	0	0	0	0	0	0	0	1	18	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0
0	8	0	0	0	8	0	0	0	0	0	0	0	1	74	0
4	11	0	0	0	15	0	0	0	0	0	0	0	1	46	0
18	41	0	1	0	60	0	4	0	0	0	4	0	4	322	0
3	15	1	0	0	19	0	1	1	0	0	2	0	0	90	0
1	11	0	0	0	12	0	1	0	0	0	1	0	0	152	0
8	18	0	0	0	26	0	5	1	0	0	6	0	0	48	0
0	7	0	0	0	7	0	2	0	0	0	2	0	0	59	0
0	5	0	0	0	5	0	0	0	0	0	0	0	0	37	0
5	36	1	0	0	42	0	10	0	1	0	11	0	4	203	0
4	21	0	0	0	25	1	17	1	0	0	19	0	0	86	0
1	10	2	0	0	13	4	6	0	0	0	10	0	0	75	0
7	52	6	1	0	66	1	15	1	0	0	17	0	0	154	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
2	12	0	0	0	14	0	1	0	0	0	1	0	0	169	0
1	7	0	0	0	8	0	2	1	0	0	3	0	0	47	0
60	292	10	2	0	364	6	64	5	1	0	76	0	11	1813	0
72	622	272	113	2	1081	15	21	2	0	0	38	46	1	1335	32
24	1656	120	52	6	2058	55	775	48	6	0	884	39	9	5083	61
96	2278	392	165	8	3139	70	796	50	6	0	922	85	10	6418	93
95	1191	183	153	127	1749	35	719	66	11	2	833	662	37	5569	33
60	292	10	2	0	364	6	64	5	1	0	76	0	11	1813	0
55	1483	193	155	127	2113	41	783	71	12	2	909	662	48	7382	33
51	3761	585	320	135	5252	111	1579	121	18	2	1831	747	58	13800	126



URE 17. Juvenile red salmon relative abundance, July, August, and September 1961—1 winter-in-the-sea fish taken in 2 1 2 and 3 3 4-inch mesh nets.

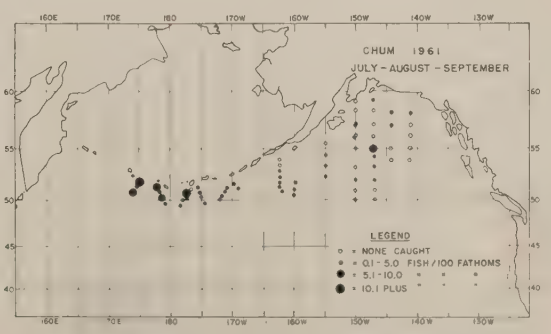


FIGURE 18. Juvenile chum salmon relative abundance, July, August, and September 1961—2-year-old fish taken in 2-1/2 and 3-1/4-inch mesh nets.

OCEANOGRAPHY

by Felix Favorite and B. A. Morse

Field Work

Physical, chemical and biological observations, similar to those obtained in previous years, were made aboard chartered vessels *Paragon*, *Marine View*, and *Windward* at fishing locations (Fig. 19).

Zooplankton investigations were conducted aboard the USC&GS vessel *Pioneer* during a cruise from Honolulu to the Aleutian Islands and return (Fig. 20). These observations will permit comparison of the abundance of food organisms in salmon waters (northward of lat. 40°N.) with the food organisms in the region to the southward, and investigations of the type and abundance of organisms in the Intermediate Water. The latter water mass, identified by a salinity minimum ($<34.0‰$) occurring at depth between the surface lens of Pacific Central Water and the Deep Water (Favorite and Hebard, 1960), is believed to originate in the Okhotsk Sea and may influence the distribution and movements of the salmons. Although the water mass exists a depth, it is continuous across the North Pacific Ocea southward of latitude 40°N. *In situ* temperatures 4° to 8°C., and dissolved oxygen values of .2 to mg. at./L seem to provide an acceptable salmo environment.

Physical Oceanography

The oceanographic data collected during 1939 t 1941 in Bristol Bay (Favorite *et al.*, 1961) have bee analyzed. A description of oceanographic condition and features in the Bay has been completed and wi be included in the Joint Report on Oceanograph being prepared for the Committee on Biology an Research. The general counter-clockwise circulatio in the Bay is widely recognized, but there appear to be an active upwelling zone at the entrance of th Bay between Cape Peirce and Port Moller. This reflected in data collected during Summer, 1940, b

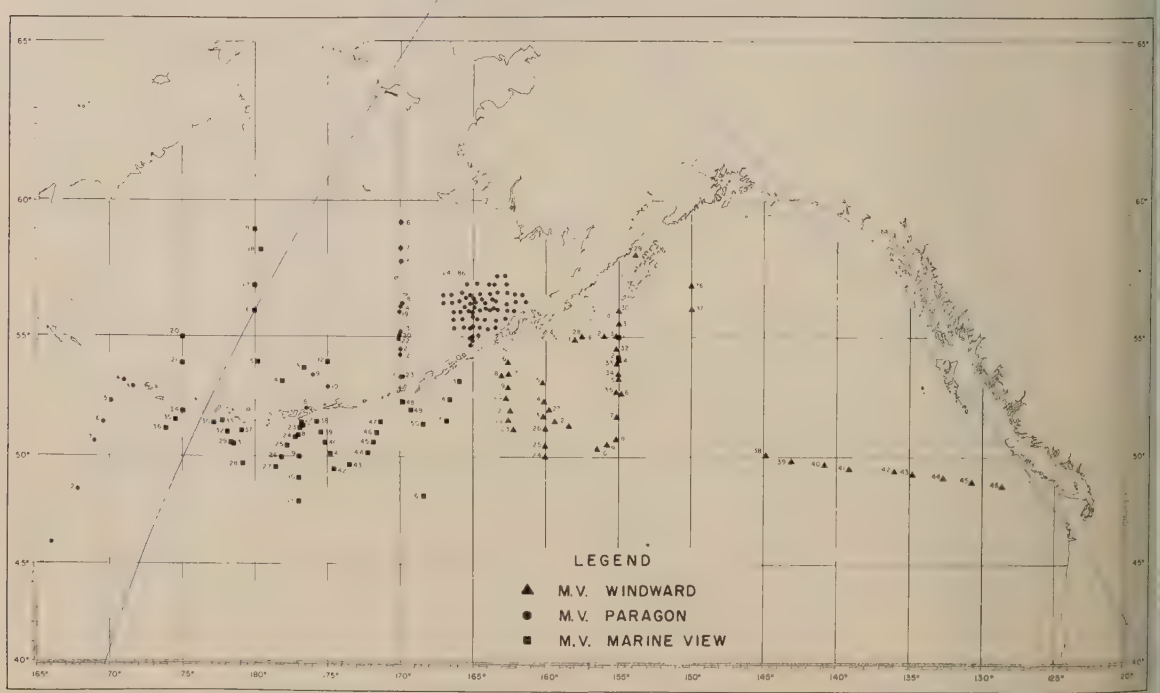


Figure 19. Oceanographic stations, 1961.

EXTRAIT

[redacted]

ICNAF Spec Pub No 4
1963
North Atlantic Fish
Marking Symposium

33.
An Analysis of Silver Hake Tag Returns

By
RAYMOND L. FRITZ*

The success of a tagging or marking experiment depends on the use of healthy, undamaged fish marked with a durable tag that will be detected readily and returned with information about the tagged fish. To achieve the planned objectives of an experiment, precise information regarding the location and date of recapture of the fish, depth of water, and other pertinent data is necessary. Generally, this information is most accurate when the tag is recovered by the person recapturing the fish. Information received from other sources is generally incomplete. However, we must often depend upon recoveries made ashore after the fish are landed. When the fish are utilized in different ways, tags will be recovered from different kinds of processing plants. Some of these are more efficient than others in detecting and reporting tags.

The silver hake (*Merluccius bilinearis*) is an example of a Western Atlantic species which is utilized by several important United States fisheries. It is used largely for human food, but substantial quantities are also used for animal food and for industrial use (fish concentrates, fish meal, and oils). This paper compares the relative success of tag recovery from these three fisheries, and compares the number of tags returned in the various stages of the fish processing system.

During the spring and summer of 1957 and 1958, tagging experiments were conducted from trap nets, otter trawls, and hook and line along the coastal waters of Massachusetts and New Jersey and offshore on Georges Bank. The tag used (Fritz, 1959) consisted of an 8-inch piece of yellow Vinyl plastic tubing with an Atkins tag tied at one end with a figure eight knot, the other end inserted through the flesh of the dorsum of the hake and knotted (Fig. 1). This is a very conspicuous tag.

Reward posters were put up at almost every processing plant, regardless of type, to notify and remind plant employees and fishermen alike of the tagged silver hake and the appearance of the tag.

Table 1 compares the returns for each of the three kinds of fisheries. The human food fishery turned in the largest number of tags, with the animal food fishery next, and finally the industrial fishery, even though more trips were made and more silver hake landed by the industrial fishery than the animal food fishery. The number of tag returns from the human food fishery was significantly greater than the others, even though the vessels from the three fisheries often fished side by side on the same grounds.

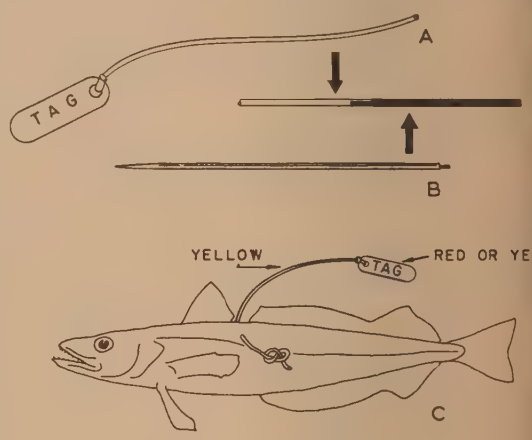


Figure 1. Tag used on silver hake.

Table 1
Comparison of returns from three kinds of fisheries

	Human food	Animal food	Industria
Total pounds landed 1957—1958 combined	182 million	36 million	43 million
Relative pounds landed	5.0	1.0	1.2
Number of trips*	2019	750	1861
Number of tags returned	222	7	1
Percent returned	4.0	0.1	0.02

* Estimated

An analysis of the data was made to determine when the tagged fish were detected, using the following categories: when caught, while unloading, during processing, by consumer, and source unknown. The results are presented in Table 2.

Since only one tag was returned from the industrial fishery no conclusion can be drawn from returns from that source, except that neither the fishermen nor the processors detect many tags in this fishery. In the animal food fishery 5 of the 7 recoveries were made by the fishermen, 1 while unloading and 1 by the consumer, the consumer in this case being the animal farmer who handled the fish while feeding his animals (mink). In the human food industry the greatest percentage of returns came from processors, with an almost equal number from the fishermen.

* U. S. Department of the Interior, Fish and Wildlife Service, Bureau of Commercial Fisheries Biological Laboratory, Woods Hole, Massachusetts, U.S.A.

Table 2
Comparison of returns, with time of detection

When detected	Human food	Animal food	Industrial use	Source unknown	Total number	Percent
:n caught	85	5	1	2	93	38.9
le unloading	16	1	—	1	18	7.5
ing processing	103	—	—	—	103	43.1
onsumer	12	1	—	—	13	5.4
nown	6	—	—	6	12	5.0
al	222	7	1	9	239	100.0

ince the vessels in the three industries often fish same stocks of fish at the same time, the difference returns from the fishermen is probably not due different percentage of recaptures but to differen- in detection in the different fisheries. The fisher- n fishing for human food grade their catch on rd and sometimes ice and box it on board. Thus, y handle the fish individually and have good portunity to see the plastic tags, whereas the ermen in the animal and industrial fisheries move fish *en masse* and have much less opportunity to ect the tags.

n the human food industry the fish are individually dled after they are landed, both in packing and preparation for eating. This explains the returns m the human food fishery at stages after unloading. is interesting to note that the ratio of the number ected at unloading to the number detected at ture is the same for the animal food fishery as human food fishery.

Total returns amounted to only 4.3 percent. viously, there is either a high mortality of tagged or a low recovery of tags. The tags are so conspicu- s that it is difficult to understand how they could ss through a packer's hands. But this they do, evidenced by the 12 tags recovered by the ultimate consumer in the human food fishery. The silver hake is not a large fish and it does not seem practical to extend the plastic tube. Future experiments may involve use of different colors and a change in the tag itself.

A higher rate of return in the industrial fishery could be effected by use of a different kind of tag which is recovered mechanically, but the expense of such machinery prohibits installation at this time.

Summary

Silver hake are landed in the U.S. for three different uses; human food, animal food, and industrial products. The fish landed for the three different purposes are handled and processed in three different ways. In 1957 and 1958, 5,495 fish were tagged. A little over 4 percent of the tags were returned, almost all from the human food fishery. This is explained by the fact that the fish in this fishery are given more individual attention on board ship and ashore than in the other fisheries.

Reference

FRITZ, RAYMOND L. 1959. A summary of hake tagging in Europe and the United States, 1931—1958. *J. Cons. int. Explor. Mer*, **24** (3): 480—485.

Schmidt & Klaunig, Kiel

APPENDIX C-11

A View of the Present Status of Spawning Channels

Harold A. Gangmark, U. S. Bureau of Commercial Fisheries

ABSTRACT

Prior to emergence of fry from the gravel, mortality of red, chum, and pink salmon has been found to average 90 percent. In the natural stream of the Sacramento area, we have found a mortality of 96 percent for chinooks primarily caused either directly or indirectly from siltation. A direct relationship between conditions in Nature for survival in the gravel and the fecundity of the native species, as suggested by Neave's theory on "differential fecundity" strongly indicates that these processes of siltation are not new nor are they entirely man-made.

Our objective in employing specialized production areas is to mitigate the inroads of man and to profit from Nature's own form of compensation which is excessive fecundity.

Advantages of improved production areas usually include: stabilized stream flow, reduced silt loads, clean gravel, gravel sizes that preclude washout of eggs, and predetermined hydraulic gradients. They can also include temperature regulation of the stream flow below impoundments. Generally speaking, the advantage of the production area is the operational flexibility that is made possible by controlled flow.

Disadvantages may include construction and maintenance costs and confinement that might limit the carrying capacity and, in one way, favor predators.

On a management scale the cost benefit of controlled flow may make such areas of controlled flow for salmon alone, prohibitive. When tied in with other benefits, however, it can become feasible. For example, the water conservation and flood control programs that involve practically every stream in northern California can provide many acres of such control flow for the benefit of salmon.

The environmental requirements for other species and for other areas should be defined, the necessary mechanics for achieving these requirements should be developed, and the contributions of such developments should be evaluated. The sequence of events leading to practical application of the specialized production principle will probably be as follows: first will come the knowledge of events that cause losses in nature; second, the definition and evaluation of limiting factors; third, the testing of remedial measures; fourth, the definition of specifications in the specialized production area; and finally the development of management techniques. At this time, the author believes that there is enough knowledge available on the freshwater requirements of salmon in the southern range to proceed on all fronts so that we might seek potential nursery streams, test prototypes, and sample new areas simultaneously.

Printed in, "Report of Second Governors' Conference on Pacific Salmon Convened by Governor Albert D. Rosellini of Washington Hyatt House, Seattle--January 7-10, 1963."

SHARKS *and* SURVIVAL

Chapter 19 Testing Shark Repellents

By Perry W. Gilbert and Stewart Springer

Chapter 19 Testing Shark Repellents

By Perry W. Gilbert[1] and Stewart Springer[2]

THE USEFULNESS OF ANY CHEMICAL COMPOUND, biological product, or physical device as a shark repellent depends in large measure on the care with which it has been tested and its effectiveness evaluated. In recent years a number of commercial preparations for repelling sharks have appeared on the market, and, although extravagant claims have been made in the advertisements for these products, very few have been rigorously tested. If this unrestrained practice is continued, disillusionment with the effectiveness of the preparation and serious damage to the reputation of the commercial firm which produces it are inevitable. It is worthwhile, therefore, to review some of the more objective methods that have been employed for testing the effectiveness of various substances which may inhibit the feeding activity of, or actually repel, sharks. These tests, conducted by impartial observers, frequently have not only provided an objective evaluation of the repellent properties of the substance tested but have also taught us much about the feeding activities and behavior of sharks.

TESTS ON CAPTIVE SHARKS IN TANKS AND PENS

The first serious scientific effort aimed at developing a repellent which would protect man against sharks was in 1942, shortly after the entry of the United States into World War II. Because quick results were essential, large numbers of sharks were needed which could be readily maintained in captivity. The smooth dogfish, *Mustelus canis*, was therefore chosen as the experimental animal, and in July 1942 one of us (Springer, 1954) began a series of experiments at Woods Hole, Massachusetts, with others in a study team.

The dogfish were collected by hook and line near the laboratory docks and were transported to the laboratory in live cars. They were immediately transferred to holding tanks in the laboratory where running sea water was available. The temperature of the sea water remained constant (within one degree) during the experimental period from July to September and may have been an

[1] Cornell University, Ithaca, New York.
[2] U.S. Fish and Wildlife Service, Stanford University, Palo Alto, California.

important factor in the success of experiments. At least one subsequent tempt to repeat these experiments at La Jolla, California, with a related spec of *Mustelus* failed, and a notable difference in the situation was the fluctuati temperature of the water supply.

The dogfish at Woods Hole were kept in the holding tanks for a few da and were fed sparingly on pieces of fresh mackerel. Small sharks, sharks w apparent injury, or sharks that refused food for several days were discarde Lots of four to six individuals were selected for experiments and transferr to the experimental tank. The experimental tank, located in the basement the Woods Hole Oceanographic Institution, was of wood, painted white insi and about 5 feet wide by 15 feet long, with running sea water maintained a depth of about 3 feet. The dogfish put into the experimental tank were f regularly at 10:00 each morning with one-inch-square pieces of filleted fre mackerel, placed on the outside of a 4″ x 4″ x 4″ wire mesh box situated ne one end of the rectangular tank. Only dogfish that fed regularly and appear to be in good physical condition were used for experiments. Dogfish caught hook and line and carefully handled were more satisfactory than were trapp and netted fish. Food was offered to the dogfish as soon as they reached t holding tanks, although they often did not feed until the second or third d after capture.

We found that our experimental dogfish normally swam slowly in elliptical course around the tank at the approach of feeding time and th spacing of the sharks was random and uniform; i.e., the sharks did not te to group together. We also found that a piece of mackerel sinking past the eyes did not interest them immediately, and that reaction to the food w delayed, possibly awaiting an olfactory stimulation.

When a one-inch square of mackerel fillet was placed inside the wire ca in the tank, we found that the intensity of the reactions of the dogfish cou be roughly classified. After detecting the food, the first swimming response each shark was an abrupt turn from its normal elliptical course around t tank to a tight circle around the food. We called this a hunting turn, althou it probably is the normal response to any stimulus leading to investigation the part of the shark. Frequently the shark returned to the elliptical cour around the tank without an attempt to close in on the bait; at other times approached and bit the wire mesh box, or even picked it up and shook it.

Since it was necessary to determine the effectiveness of a great many m terials, at least on a comparative scale, the following biological assay w employed to determine the extent to which various substances inhibited t feeding activity of the dogfish. We arranged a series of tests, each test to r for ten minutes. The first test and alternate tests thereafter were made using piece of mackerel inside the wire box. The second test and alternate tests ther after were made with a piece of mackerel inside the box in addition to t material being tested. A rest of ten minutes or more was allowed after ea test, and the wire box with its content was removed from the water at the e of the test. Fresh food was used for each test. The turnover of water in t

...luring the period between tests was far from complete, and the accumu-...s of dissolved materials from the food and from the materials being tested ...bly were sources of error. For each test one or two observers who had ...ed the dogfish long enough to recognize them as individuals were given ... cards. They were told to score numerically the results at the end of each ...e on the entirely arbitrary basis of one point for each hunting turn made ...y dogfish during that minute, two points for any dogfish biting the wire ...nd five points for any dogfish picking up the box and shaking it.

...e figures were convenient because the total for a ten-minute test using ...alone was always a figure near 100, and because the results were reason-...consistent from day to day with different observers. The figures also were ...nient because, by comparing the figure for any given substance being ...with the mean of the preceding and following tests which were always ... with food alone, we could arrive at a figure which we regarded as the ...ntage of effectiveness for that particular series of tests.

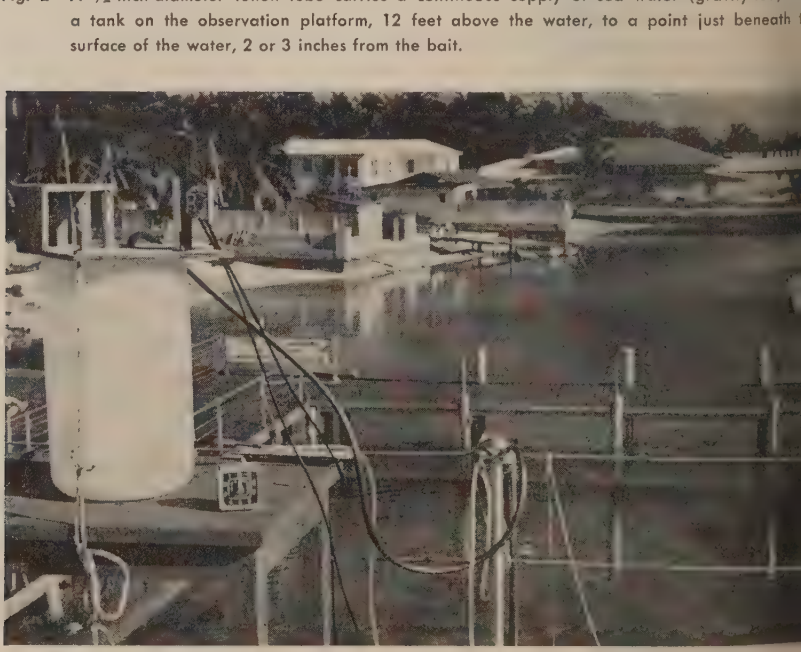
...ere were several interesting trends in these test series. Testing was or-...ily started at ten in the morning, and a series of tests were made without ...uption except for ten-minute rest periods. The values obtained for con-... i.e., for tests with food alone, increased regularly for one to two hours ...then decreased. The increase, reflecting increasing response on the part ...e dogfish, normally reached a figure about 20% higher than the starting ...e. Ordinarily we stopped testing for the day after figures for control tests ...ned to the starting figure. Only once were the tests continued beyond this ... On that occasion, about four hours after the testing started, the dogfish's ...onses became so weak that there was no sharp distinction between controls ...ested materials.

... wide variety of chemical compounds, biological products, and physical ...ts, including fish poisons such as rotenone, irritants such as chlorine, ...llic poisons, chemical stenches, and poison gas generators, were tried on ...experimental groups of sharks. In general, the Woods Hole tests indicated ... almost any substance even slightly soluble in sea water and not a food ...ced the feeding responses of the dogfish. A few substances were neutral or ... slightly attractive. Very few substances strongly reduced the responses. ...ral of the organic acids, notably maleic acid and malic acid, occasionally ...bited feeding completely, but results were not consistent. The most con-...nt results were obtained by use of shark flesh allowed to stand at 20° C ... four to six days and with small concentrations of copper salts. Ethyl ...hol extracts of four- to six-day-old shark flesh inhibited the dogfish feeding ...onses, but the results with extracts were not so dependable as those with ...mposed shark flesh.

...he story of the analysis of decomposed shark flesh and subsequent develop-...t of the U. S. Navy repellent known as Shark Chaser is told elsewhere in ... volume. On several occasions in recent years, one of us (Gilbert) has ...ed a wide range of biological products and chemical compounds, including ... components of Shark Chaser — copper acetate and nigrosine dye. Captive

Fig. 1 The bait (2-pound oceanic bonito or Spanish mackeral tied by its caudal peduncle to operating string is presented to the sharks for three 3-minute periods. After each 3-min presentation period, there is a 2-minute rest.

Fig. 2 A ½-inch-diameter teflon tube carries a continuous supply of sea water (gravity-fed) fr a tank on the observation platform, 12 feet above the water, to a point just beneath t surface of the water, 2 or 3 inches from the bait.



All movements of the sharks are diagrammed or recorded on movie film and tape, and approaches to within 1 foot of the bait are counted as 'passes'.

At the end of the third 3-minute presentation period, without any rest period intervening, the chemical or extract to be tested is injected into the teflon tube. All movements of the sharks are recorded during the 3-minute test period, and the number of 'passes' is compared with that of the 3-minute presentation periods.

adult lemon (*Negaprion brevirostris*), tiger (*Galeocerdo cuvieri*), b (*Carcharhinus leucas*), dusky (*Carcharhinus obscurus*), sandbar (*Carc rhinus milberti*), and nurse (*Ginglymostoma cirratum*) sharks, all in good c dition, have been used at various times in the testing program. The shar located in 40′ x 80′ wire enclosures (Fig. 1 and 2) in the lagoon at Bim Bahamas, could be readily observed from a viewing platform 12′ above water at one end of the enclosures. The procedure in testing a given substa for feeding inhibition and repellent effect is as follows:

1. Adult sharks, ranging in total length from 6 to 15 feet, are utilized in bioassays.

2. At least four sharks are employed in each bioassay, since one shark alo in the pen does not readily approach the lure and attempt to attack it, as a ru

3. Bioassays are run whenever possible at slack tide so that chemicals extracts to be tested will not be flushed through the pen too rapidly.

4. Prior to the presentation of the lure and/or chemical, the movements the sharks in the pen are diagrammed for three 3-minute control periods.

5. At the end of the third 3-minute control period, a lure (usually 2-pound oceanic bonito or spanish mackerel tied by its caudal peduncle to operating string) is presented to the sharks for three 3-minute periods. tween each 3-minute presentation period there is a 2-minute rest period. submerged lure, situated midway between the east and west side of the pen a 20′ from the observation platform, can be drawn vertically out of the wa at will by a string.

6. A $\frac{1}{2}$-inch-diameter teflon tube (which is chemically inert) carries a c tinuous supply of gravity-fed sea water from a tank on the observation pl form, 12 feet above the water, to a point beneath the surface of the wat 6–12 inches from the lure.

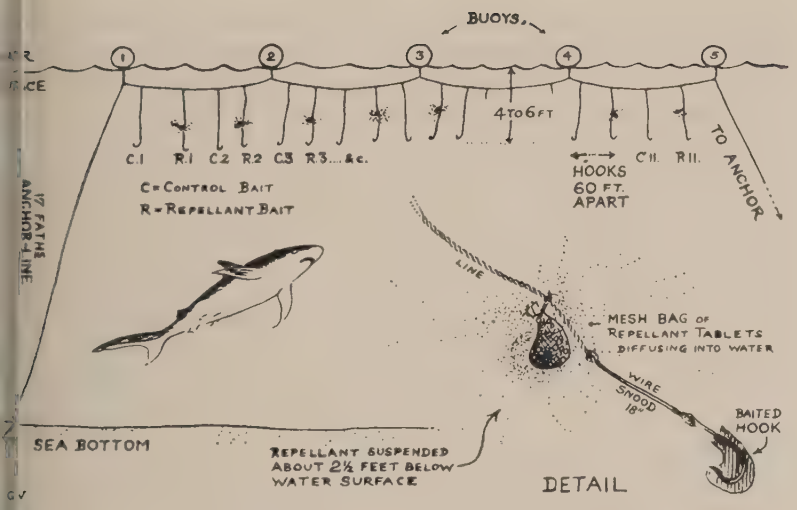
7. Whenever attack on the lure is imminent (head of shark within 6 inc of lure), the lure is drawn out of the water.

8. All movements of the sharks are diagrammed or recorded on mo film and/or tape, and approaches to within 1 foot of the lure are counted "passes" (Figs. 3 and 4).

9. At the end of the third 3-minute presentation period, without any r period intervening, a known quantity of the chemical to be tested is inject with a hypodermic syringe into the upper end of the teflon tube (Fig. 2). T chemical, carried along by the sea water flowing continuously in the tube, thus delivered into the vicinity of the lure with no change in turbulence. T only variable which is introduced about the lure is the presence of the chemic

10. The behavior of the shark with respect to the lure, now enveloped the chemical, is documented, and the number of passes to within 1 foot the lure is recorded as in the control periods. In this way the effectiveness a chemical compound or biological product is evaluated as a *feeding inhibit*

11. Chemical compounds and biological products are also presented to t sharks in much the same manner, but without a lure, for three 3-minu periods. If sharks at first sense the presence of the substance introduced a



A typical rig of the set line used in shark-repellent tests. (From Whitley and Payne, 1947.)

assiduously avoid the area of introduction, the substance is considered to some value as a *repellent*. Degrees of repulsion (strong, medium, weak), s l on the behavior pattern of the sharks, are recorded, as well as the dura- of the repellent period.

. Careful note is taken in the above procedures of the quantity of material duced and its approximate dilution (determined with a spectrophotom- in the water at the time it effectively repels or inhibits feeding.

e have found that copper acetate fails to repel or inhibit the feeding ac- es of the several species of sharks we have worked with at Bimini. On the h hand, nigrosine dye functions as both a feeding inhibitor and repellent l species except the nurse shark; the latter enters a dense cloud of nigrosine nd feeds with no hesitation within it. Extracts of decomposed shark flesh, cared by Dr. Maynard Steinberg and his staff at the U. S. Fish and Wildlife nological Laboratory in Gloucester, Massachusetts, neither repel nor hit the feeding activity of any shark with which we have worked at Bimini y shark with which Dr. Albert L. Tester and his colleagues have worked awaii and Eniwetok. Yet decomposed shark flesh is known to effectively hit the feeding activity of smooth dogfish (*Mustelus canis*).

FIELD TESTS ON SHARKS IN THE OPEN SEA

hile tests conducted in tanks and pens on captive sharks can be more care- observed and controlled, the effectiveness of any repellent must be ulti- ly established for sharks in the open sea. Here, after all, is the locale where epellent must be used by survivors of air and sea disasters. It is of interest, fore, to review the testing procedures which have been thus far employed e open sea (Fig. 5).

In January–February 1943, copper acetate was tested in the Gulf of Guay quil, off Ecuador, South America. The tests are described by Mr. William Burden, Responsible Investigator in charge of the operation, as follows:

> At least three species of sharks were present in this locality: the black-tipp ground shark (*Carcharhinus aethalorus*), the hammerhead shark (*Sphyr corona*), and another ground shark (*Carcharhinus azureus*). These sharks f voraciously every day on the incoming tide. Their source of food was mul and there was evidence that this bait was far more attractive to them than a freshly killed mammal. Accordingly the experiments were conducted using m let for bait. The boat was equipped with two bamboo outriggers. Bait was su pended 18 to 24 feet deep and allowed to drift astern one from each outrigg and one from the stern of the boat. The depth at this location was approximate 40 feet. The three baits were at least 30 to 40 feet apart. A 2-lb. diffusion b of the chemical under test was tied 2 feet above one of the baits. Counts we then made of the number of shark strikes on each of the three lines during th course of the experiment. The counts were only recorded when unquestionab evidence was secured that a shark was responsible for the strike. This eviden consisted either in actually hooking the shark or in the unmistakable characte istic shark-tooth marks when the bait was cut in half.
>
> The extract from decomposing shark meat under field conditions gave u satisfactory results in that the bait with the repellent was taken on 5 occasions.
>
> The findings for the maleic acid were also unsatisfactory in that the bait wi the repellent was taken 6 times.
>
> However, copper sulphate gave far more promising results. The bait with th repellent was only taken once out of 15 times when the rate of diffusion was least $\frac{1}{2}$ pound per hour. When the rate was below that figure, the bait with th repellent was taken 3 times and the controls 7. This indicates marked repelle value for copper sulphate but in quantities too great for practical purposes.
>
> The tests for copper acetate were 100 per cent satisfactory. The bait with th repellent was never touched while the controls were taken 26 times.

Additional tests were conducted in 1943–44 off the east coast of Florid in the Florida Keys, and in the Gulf of Mexico, by Lt. J. M. Fogelberg and h team. Since Fogelberg's report (NRL Report No. P-2230), recently declass fied, is not generally available, the following quotation will be of interest:

> The field testing of shark repellent materials was originally begun by th Laboratory as a cooperative effort with the Committee on Medical Research t determine the most satisfactory means of using the copper acetate for which th investigators for the committee had already demonstrated shark repellent qual ties. The early testing by this Laboratory was concerned, mainly with determinir the rate and uniformity of solution of the repellent unit under conditions repr senting those met with by a man in a life jacket drifting in the open sea and als determining the diffusion pattern of the dissolved material in the region surroun ing the man.

When it became evident that the protective zone formed by the repellent in the water was much more limited in area than had been assumed, further testing of the repellent value of copper acetate under various conditions was undertaken. The results of the latter tests showed that under certain conditions copper acetate was much less effective than was indicated by the original tests. Field tests were conducted with other materials and a material was evolved that showed a greater over-all effectiveness than copper acetate and that lent itself more readily to formulation into an acceptable repellent unit.

The solubility characteristics of the repellent units were determined by suspending them one foot below a weighted drifting life jacket in the open sea. The temperature of the water varied between 70° and 80° F. The rate of solution was dependent on the composition of the repellent unit and to a limited extent on the choppiness and temperature of the water. The extent of diffusion of the dissolved material in the case of the copper acetate was determined by chemical analyses of water samples taken at various distances and depths from the drifting jacket to which the repellent was attached.

In the case of repellents containing dyes the pattern of diffusion was studied by visual and photographic means. The principal factors influencing the diffusion pattern were found to be (1) the drift of the jacket due to wind, (2) the bobbing of the jacket brought about by wave action and (3) diffusion due to movement of the water particles in wave action. The rate of drift of the jacket due to wind was in most cases sufficient to produce a ribbon-like diffusion pattern extending from the jacket in the direction from which the wind was blowing. It was the observance of this unidirectional characteristic of the diffusion pattern that demonstrated the difficulty of creating a protective zone about the man in a jacket. The material used might be an excellent repellent but if the shark did not encounter it before attacking his prey it would be of little value. This possibility was one of the reasons for carrying out additional field tests on the repellent value of copper acetate.

The repellent value of a substance obviously could not be determined by actual survival tests with humans. A method of determining the ability to protect baits similar to that used by the original investigators was used to evaluate the effectiveness of the repellent substances. Two shark lines were used simultaneously, identical except for the presence of a repellent unit on one line, the other line acted as a control. The baits on the hooks were suspended at the desired depth by means of floats. The lines were fished from the stern of an anchored boat and were kept separated a distance of 25 to 50 feet by means of outriggers and small paravanes.

The effectiveness of a substance for protecting baits was calculated according to the following relationship:

$$\frac{\text{number on control minus number on repellent}}{\text{number on control}} \times 100 = \%\ \text{effectiveness}$$

The numerator represents the best estimate of the number repelled and the denominator the number that would have been caught had there been no repellent. The term "percent effectiveness" is subject to random errors just as are the num-

ber of catches and strikes and should only be considered when calculated fr sufficiently large numbers to be judged significant.

Line tests were conducted in the vicinity of St. Augustine, Florida; Bilo Mississippi; and the Florida Keys. Series I, II and III are tests of the repell value of copper acetate. Series IV are tests of the repellent value of a dark wa soluble dye, WBSR. In all cases, the rate of solution was approximately 30 gra of repellent per hour.

Series I

Tests conducted at North River, St. Augustine, Florida, ? July 1943 betwe hours of 1930 and 0500.

Rigs	Two similar rigs used, one of which was protect with repellent cake. Floats used so that baits hung fr 5 to 15 feet below the surface and repellent cake w attached 30 to 48 inches from bait.
Bait	Fresh shrimp.
Repellent	Copper acetate.
Type of Sharks	Small hammerhead and shovelnose.
Results	Number of sharks caught on control line . . . . . Number of sharks caught on repellent line . . . . . Percent effectiveness . . . . .

Series II [1]

Tests conducted at Chandeleur Island, Louisiana, off Biloxi, Mississippi, July 1943 to 8 August 1943 between hours of 0730 and 2000.

Rigs	Two similar rigs used, one with repellent cake. Flo used to suspend baits about 3 feet below surface. R pellent cake attached 30 inches from bait.
Bait	Fresh white trout and ground mullet.
Repellent	Copper acetate.
Type of Sharks	Black tip and one sharp nose, other types includi hammerhead, lemon shark and tiger shark, known be in vicinity.
Condition of Sharks	The sharks were stirred up and brought to the surfa by dragging a shrimp trawl and by chumming. T tests have been divided into two parts arbitrarily the basis of rate of fishing. During the period great shark activity the sharks often struck the bait few seconds after it struck the water and it is possib that some of the sharks attacked the bait without e countering any of the repellent.

[1] The test represented by Series II was conducted by the Committee on Medical R search with the cooperation of a representative of the Naval Research Laboratory.

esults

	Control[2]	Repellent	Percent effectiveness
Period of great shark activity	67	37	45
Period of lesser activity	46	11	76
Combined periods	113	48	58

Series III

Tests conducted at Florida Keys off Bahia Honda Channel, 12 October and 1 December 1943 during hours of 1000 and 2000.

igs — Two similar rigs used, one with repellent cake attached 36 inches from bait. Floats used to keep baits about 12 feet below surface.

ait — Fresh mullet.

epellent — Copper acetate.

ype of Sharks — Black tip, sharp nose and black nose. One large nurse shark caught on non-experimental rig.

ondition of Sharks — Efforts made to attract sharks to vicinity by occasional chumming with chopped mullet and bottom fishing for other fish. Exploratory catches made to show presence of sharks in vicinity.

esults

	Catches	Strikes	Totals
Exploratory catches	8	0	8
Control line	12	4	16
Repellent line	1	0	1
Percent effectiveness	92	—	94

Series IV

Tests conducted at Florida Keys within a radius of 25 miles of Marathon, lorida during all hours including hours with bright moon and no moonlight onditions.

igs — Two similar rigs used, one with repellent cake and the other with dummy bakelite cake. Repellent cake attached 36 inches from bait. Floats used to keep baits 3 to 15 feet below surface.

ait — Fresh mullet.

epellent — Dyestuff Calco WBSR.

ype of Sharks — Black tip, shovelnose, black nose and sharp nose.

mbers include both catches and strikes.

Condition of Sharks Occasional chumming with chopped mullet. Simulta ous fishing for bottom fish. Exploratory catches ma to show presence of sharks in vicinity.

Results

	Catches	Strikes	Combin
Exploratory catches	114	4	118
Control line	50	23	73
Repellent line	2	0	2
Percent effectiveness	96	—	97

In the comparison of the relative effectiveness of copper acetate and the bl dye Calco WBSR, the results from the period of great activity in the Bil tests of Series II are not included since, as yet, we have no corresponding peri of such activity in the results for dye WBSR. Excluding the data just mention the effectiveness of copper acetate as calculated from Series I, II and III is 78 with a total of 106 strikes and catches being considered. The effectiveness 97% obtained for dye WBSR represents a total of 75 strikes and catches.

Another kind of test procedure was carried out near Marathon, Florida 12 January 1944 and is summarized as follows.

1st fishing period 100 minutes, 2 rigs used without repellent.

Sharks caught	12
Strikes	9
Greatest interval between actions	13 minutes

2nd fishing period 100 minutes, 2 rigs used each with Calco WBSR d cakes.

Sharks caught	0
Strikes	0
Greatest interval between actions	100 minutes

3rd fishing period 58 minutes, 2 rigs used, each without repellent.

Sharks caught	4
Strikes	2
Greatest interval between actions	21 minutes

In this case the baits were suspended about 5 feet below the floats and th rigs were of the type described for test Series IV. Finely chopped mullet we used for chumming and the chumming was maintained at a relatively consta rate throughout the test. There was no interval between experiments. The grea est interval between actions, a catch or a strike, gives some indication of th response of the sharks. This response was entirely stopped by the presence the repellent but the recurrence of response even though in somewhat less degree during the check period after withdrawal of the repellent indicates th sharks were present, at least in the general vicinity, throughout the entire tes

Discussion of Coordinated Results

mparison of the Effects of Copper Acetate and Dyestuff in Shark Behavior

is difficult to make any factual statement regarding the relative importance of e visual stimulus and the olfactory stimulus in the feeding habits of sharks. so, the part played by each is probably not constant but changes with condi- ns and degree of excitation of the sharks.

One of the important differences between these two stimuli as far as a search r a repellent substance is concerned, is that actual contact must be established th a substance in order for it to be detected by the olfactory sense, whereas tual contact is not necessary to produce a visual response. It was pointed out at the failure of the copper acetate during the period of excited feeding could ry well have been due to the fact that the shark did not encounter the repellent fore taking the bait, or did not encounter it in sufficient time for him to re- ond to the olfactory stimulus produced by the repellent. Copper acetate, in e concentrations met with in the tests of it as a repellent, is practically color- ss in sea water and probably cannot be detected by the visual sense of the ark. Results of the tests indicate, however, that it must definitely affect the factory sense.

It was not expected that the dark dye, Calco WBSR, would produce any more an a visual stimulus in the dilutions met with under field conditions, but the ıccess of fishing tests made on moonless nights indicated that even under these onditions, the visual stimulus remained sufficiently strong to be effective, or ıat some other response was being produced by the dye.

The effectiveness of copper acetate as a repellent decreases with increased ctivity of the sharks. This can be observed from the results of the Biloxi tests f Series II, where a value of 45% effectiveness was obtained for the period of reat activity while a value of 75% was obtained for the relatively quiet period llowing. The loss of effectiveness with increased shark activity was further emonstrated by the results of McBride and Schmidt in work with the shrimp eet off St. Augustine, Florida, in May 1943. At that time sharks in large umbers followed the shrimp boats to take the trash fish thrown overboard. 'opper acetate, in aqueous solution, when sprayed on the surface had little ffect in preventing the sharks from coming to the surface to take the trash fish s soon as they hit the water.

Tests with dark dyes, however, indicate that they possess good repellent ualities against the excited sharks on the surface. Off Biloxi, Mississippi, in August, and off Mayport, Florida in September 1943, tests were carried out vhich showed that dark dye solutions when sprayed on the surface possessed ood effectiveness in protecting floating trash fish that would ordinarily be readily ttacked by sharks. Unfortunately, these tests were not sufficiently extensive or uantitative to allow evaluation on a statistical basis with other tests of a similar haracter. The observations were that in an area where trash fish had been re- eatedly attacked by excited sharks on the surface, similar trash fish were left ntouched as long as they remained in the protective coloration of the dyestuff.

The ability of the dark dye to inhibit shark feeding under different degrees of xcitation does not necessarily mean that it is capable of affecting all of the enses that play a part in the feeding behavior of the shark. The ability to

inhibit feeding under the different conditions does indicate, however, that response or responses produced by the dark dye are sufficiently strong under conditions to overcome or largely counteract the natural stimuli that prom feeding.

A substance that depends for its repellent ability on its effect on one se alone, must necessarily suffer a decrease in efficiency when the importa of that sense is shifted into the background by some environmental change substance or combination of substances whose effectiveness depends on stimulation of several senses would be certainly less likely to suffer a large crease in efficiency as the relative importance of the various senses is chan by external conditions during the search for food.

It is not the purpose of this discussion to minimize the effectiveness of cop acetate as a repellent specific to a certain response, but rather to point ou reasonable explanation for its variation in efficiency under conditions wh probably require the combat [*sic*] of other responses.

The Calco WBSR dyestuff was shown to be effective under conditions t indicate that its effectiveness is largely derived from its ability to inhibit visual response but its ability to inhibit other responses was not so clearly in cated. For that reason, 20% copper acetate has been included in the final forn lation. As has already been mentioned, it was possible to include copper acet to the extent of 20% without sacrificing the desirable solubility characteristics the repellent material.

The Psychological Influence of Shark Repellents on the User The relatio ship of the fear of shark attack to the functional efficiency of personnel oper ing in tropical or shark-infested waters is beyond the scope of this repo Judging from what reports have been received at this Laboratory, there apparently a definite psychological problem in this respect which could relieved, at least in part, by the knowledge on the part of the individual that possesses an efficient weapon to combat even an unseen enemy.

With the use of dyestuff in the shark weapon this confidence is strengthen by the screen of blackened water which results immediately upon contact of t material with water. The color extends downward about 4 feet.

Another type of field test, described by Whitley and Payne (1947), w conducted in Australia. Their account follows.

In 1944, a joint Royal Australian Navy and Royal Australian Air Force Co mittee in Melbourne required tests of substances which had been evolved American, New Zealand and Australian chemists to ascertain whether or n they would repel sharks. Flight-Lieutenant G. H. Payne, R.A.A.F., Melbourn did the chemical work; Mr. G. P. Whitley, Research Officer, C.S.I.R., Division Fisheries, organised the expedition and identified the sharks; Mr. James Goo lad, Fisheries Inspector of the W.A. State Fisheries Department, was in char of fishing and boat operations. The R.A. Navy arranged for gear to be provid and the R.A.A.F. arranged for transport and air travel; Mr. S. Fowler, of t C.S.I.R., Division of Fisheries, performed helpful aerial reconnaissance in R.A.A.F. aeroplane. An Army observer, Major C. S. Murray, accompanied on some of our cruises.

After a series of preliminary chemical tests had been conducted at the University of Sydney, experimental batches of repellant tablets were manufactured in Melbourne and practical tests carried out in the appropriately named Shark's Bay, Western Australia. This area was chosen as being most suitable for the conducting of controlled experiments and because the sharks frequenting those waters were representative of those species met with in the waters of Pacific operational areas.

The tests were carried out from a 70 ft. lighter, and were conducted during seven cruises of from two to six days' duration each, between July and September, 1944.

A line up to half a mile in length was anchored at each end across the direction of the prevailing current, and fitted with buoys in such a way that for most of its length it was a few feet below the surface. Large jewfish hooks, baited with fresh fish, were usually set 60 ft. apart at depths of four to six feet below the surface, each alternate bait having suspended just above it a meshed bag of repellant tablets which immediately on immersion dyed the water in the vicinity. (The "Shark-Chaser" Unit developed by the U. S. Army was of different design but similar principle.)

Various rigs of floating set-lines were used, the idea being for each bait to simulate an airman floating in the water, with charges of repellants (of one or more kinds) and "control" baits with no repellant at all (Fig. 5).

Sharks were encouraged into the vicinity of the test-lines by the blood of captured sharks, turtles, and dugong, all of which were used as bait, in addition to snapper, mullet and other fishes. The big majority of the catches was made at night, and removing two or three resentful 10 ft. sharks from somewhere along half a mile of line on a cold and windy midnight was not without excitement.

During the 500 hours for which the lines were down, for one hundred experiments, a total of 50 sharks were caught. Of these, 80 per cent were caught at night (between 1700 and 0700 hours) and 20 per cent by day (0700 to 1700 hours) catches being nearly three times as frequent during hours of darkness as during the daylight hours. The tides did not make any apparent difference to sharks feeding, only a few more than half of the sharks being taken on the ebb tide.

The sharks caught ranged from $3\frac{1}{2}$ to $12\frac{1}{2}$ feet in length, mostly around the 6 ft. mark, and belonged to three genera, all suspected as potential man-eaters, and likely to be encountered in operational areas northwards of Australia or in the Western Pacific. In order of abundance, our results were:—

Species	Percentages of strikes
Tiger Sharks, *Galeocerdo cuvieri*	34
Sand Sharks, *Galeolamna dorsalis*	34
Blacktails, *Longmania calamaria*	12
Whalers, *Galeolamna greyi cauta*	4
Sharks escaped, or baits with shark-bite marks	16

Some of these species were new to science at the time, but have recently been described and figured in the "Australian Zoologist."

The repellent materials were in the form of small tablets and consisted two types, made up essentially of a black dyestuff[2] (type A or "black magi and copper acetate[3] (type B) respectively. A repellant charge consisted of ei 3 oz. of type A alone or a combination: 3 oz. of type A plus 4 oz. of type The life of a repellant charge was found to vary according to strength of cur and roughness of water and size of tablets.

Generally the 3 oz. charge of dye tablets would last at least 12 hours wh the life of the copper acetate charge was between three and four hours.

We, therefore, had to overhaul all our hooks and lines at 3-hourly interv day and night, wet or fine, to replace dissolved charges and record results. T was arduous, and even the interim routine work of washing bags, and weigh or counting out the tablets, whose pungency was irritating, were tests of patience. Then the struggles of man-eaters, hauled into our little dinghy clubbed on the nose, often tangled the lines so much that they had to be dum aboard the lighter, the numbered hooks carefully sorted, and results analy before the next set, this work sometimes having to be done by lamp-light. T sharks were each dissected afterwards and information on their feeding breeding obtained.

The effectiveness of a repellant was calculated according to the follow formula:

$$\frac{\text{Number of sharks on control minus number on repellant}}{\text{Number on control}} \times 100 = \%\ \text{effectiveness.}$$

An observed strike by a shark was counted, even though the shark may have been hooked and landed. Thus, using A type alone, we found on repell baits 9 sharks, on control baits 19, giving effectiveness of 52.6 per cent; us A + B, on repellant baits 1, on controls 21, giving an effectiveness of 9 per cent.

The possible effects of the chemical repellant on a man in water were tes by swimming submerged and with open eyes through water impregnated w repellant. No ill-effects were suffered.

A further point of interest is that, whereas sharks would not take a bait the vicinity of the repellant, no trouble was experienced in hooking snapper a other table fish on ordinary hand-lines to which a shark repellant had been t just above the bait. Neither did repellant placed in shallow water thickly po lated with tiny school fishes harm them in any way, and no complaints w made by fishermen that their livelihood was affected by our experiments.

The work was at times greatly facilitated by aerial spotting. Obviously sha as well as schools of fish are more readily located from the air than from wa level, and with a plane from the nearest R.A.A.F. stations periodically fly over the area to locate concentrations of sharks, we were able to conduct tests with a minimum of time lost in blind searching.

[2] The dye used in our Western Australian experiments is known in the trade as "Met Leather Black D.G.," a mixture of several basic dyes whose formulae are not revealed the makers. The main merit of repelling sharks is, however, credited to the copper aceta and not to the dye, though the deep staining of the water by the latter would doubtl have a comforting psychological effect on a stricken swimmer.

[3] Normal copper acetate, $Cu(C_2H_3O_2)_2, H_2O$.

As a result of these tests, it has been conclusively shown that the materials ted possess properties repellant to the varieties of sharks most common in estern Australian waters. Tests by other workers having shown that similar terials are effective against sharks frequenting the waters around Ecuador d Florida, and in New Zealand and elsewhere, it seems reasonable therefore conclude that a universal shark repellant material has been discovered and issue to the R.A.A.F. as a result indicated that airmen forced to bale out er shark-infested waters had at least one less hazard to face in their struggle regain safety.

CONCLUSIONS

om the foregoing accounts it is clear that several methods, no one of which allible, may be employed in evaluating the effectiveness of a chemical com-nd, biological product, or physical agent as a shark repellent. In general, nical compounds may be tested in much the same manner as biological ucts. On the other hand, special tests must be devised for physical agents a bubble curtains and electrical devices (see Chapter 18). To adequately uate the repellent effectiveness of a given substance, several kinds of tests be needed, even though some test series appear to give definite and quivocal answers. Regardless of what type of material or device is being d, the following points should be kept in mind:

Tests on captive sharks in tanks or pens should be supplemented by tests harks in the open sea.

To insure aggressive behavior and more active feeding, tests should be ducted with groups of sharks rather than solitary ones.

. When several sharks of the same species are employed in a test, one has opportunity to observe significant variations in the species behavior pattern. tiger shark out of twelve, for example, was repeatedly turned by a bubble ain at Bimini, while the other eleven tiger sharks promiscuously swam and forth through it.

. If several chemicals are being tested, there must be adequate rest periods he sharks between tests. In tank or pen tests, for example, the presentation ore than four chemicals in any one day to the same group of sharks is not mmended.

. Care should be used in administering the chemical compound or biologi-product in known dilutions and in uncontaminated vehicles. Teflon or glass ng is preferable to rubber or polyethylene tubing, since both rubber and ethylene readily absorb many chemicals and would thus contaminate sub-ent materials which pass through.

. Tests should be conducted on several species of sharks, since there is ation in the response pattern between species. Smooth dogfish, for example, inhibited from feeding by decomposed shark flesh, while many other sharks not. Nurse sharks are not repelled by nigrosine dye, while most other cies are.

7. Substances should be tested on sharks which are actively feeding if possible, also on sharks in a "feeding frenzy." If, however, a substance does not work when sharks are in the latter condition, it does not mean that useless. A substance which will repel a curious or circling shark is of consi able value. Shark Chaser fulfills this latter function quite well for most spe

8. Tests should be conducted at various times of day and night. Most sh are more active and feed more voraciously in the evening and at night.

9. Tests should be conducted with sharks in different parts of the worl different times of year, and at known water temperatures. Water tempera has much to do with the feeding activity of many species of sharks.

LITERATURE CITED

Burden, W. D., 1943. Shark repellents. Committee on medical research of office of scientific research and development, Progress report No. 5 (min graphed), p. 1–21.

Fogelberg, J. M., and F. E. Brinnick, 1944a. First partial report on the us chemical materials as shark repellents. NRL report No. P-2230 (min graphed), p. 1–35. Naval Research Laboratory, Anacostia Station, Wash ton, D. C.

Fogelberg, J. M., 1944b. Final report on the use of chemical materials as sh repellents. NRL report No. P-2373 (mimeographed), p. 1–28. Naval search Laboratory, Anacostia Station, Washington, D. C.

Gilbert, P. W., 1958. The present search for a shark repellent. Abstract paper presented at the Annual Meeting of the American Society of Icht ologists and Herpetologists, University of Indiana, August.

Gilbert, P. W., 1960. Shark repellents. Technical report to Biology Bran Office of Naval Research, covering period June 1, 1958–December 31, 1 (mimeographed).

Gilbert, P. W., 1961. Procedure for testing various chemicals for feeding hibition on sharks at the Lerner Marine Laboratory, Bimini, Bahan Technical report (mimeographed) distributed at Conference on Anti-sh Measures, Tenth Pacific Science Congress, Honolulu, Hawaii.

Springer, S., 1943. Sharks and their behavior, with particular reference eight genera implicated in reports of attacks on man. Technical Rep (mimeographed), Coordinator of Research and Development, USN, En gency Rescue Equipment Section.

Springer, S. 1954. Laboratory experiments with shark repellents. *Proc. Gulf Caribbean Fisheries Inst. 7th Ann. Sess.*, p. 159–163.

Tester, A. L., E. S. Hobson, and S. Kato, 1961. Summary of research on a shark measures conducted by the University of Hawaii. Technical rep (mimeographed) distributed at Conference on Anti-shark Measures, Te Pacific Science Congress, Honolulu, Hawaii.

Tuve, R. L., 1947. The technology of the U. S. Navy "Shark Chaser." *U. Naval Inst. Proc.*, **73**(5):522–527.

Whitley, G. P., and G. H. Payne, 1947. Testing a shark repellent. *Austral Zool.*, **2**(2):151–157.

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From Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species. FAO Fisheries Reports No. 6, Vol. 3, P. 1621-1631. 1963.

Experience Paper No. 36

THE OLFACTORY ORGAN OF THE SKIPJACK Katsuwonus pelamis

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Abstract

The morphology and histology of the olfactory organ of the skipjack tuna Katsuwonus pelamis (Linnaeus) are described. The olfactory apparatus consists of an olfactory chamber, containing an olfactory rosette, and an accessory sac which functions as a pumping apparatus. No cilia are present. Olfactory sensory hairs on the rosette epithelium were demonstrated.

Experiments to determine the flow of water through the olfactory apparatus demonstrated that water flows through the olfactory chamber owing to forward progression of the fish, and that an additional increment of water is probably drawn into the chamber by the accessory sac when the jaws are opened.

It was concluded that the skipjack has a potentially functional olfactory organ.

L'ORGANE OLFACTIF DE LA BONITE A VENTRE RAYE Katsuwonus pelamis

Résumé

On décrit la morphologie et l'histologie de l'organe olfactif de la bonite à ventre rayé, Katsuwonus pelamis (Linnaeus). L'appareil olfactif comprend une chambre olfactive, contenant une rosette olfactive, et un sac accessoire qui fonctionne comme une pompe. Il n'y a pas de cils. L'article décrit la chevelure sensorielle olfactive de l'épithelium de la rosette.

Des experiences destinées à mesurer le passage de l'eau à travers l'appareil olfactif a montré que l'eau passe dans la chambre olfactive grâce au mouvement du poisson, et qu'une quantité supplémentaire est probablement amenée dans la chambre par le sac annexe lorsque la bouche du poisson est ouverte.

On en conclut que la bonite à ventre rayé à un organe olfactif potentiellement fonctionnel.

EP/36

EL ORGANO OLFATORIO DEL BARRILETE *Katsuwonus pelamis*

Extracto

Se describen la morfología e histología del órgano olfatorio del barrilete *Katsuwonus pelamis* (Linnaeus). El aparato olfatorio consiste en una cámara en la que se aloja la roseta olfatoria y un saco accesorio que funciona como una bomba. No existen cilios. Se ha demostrado la existencia de pelos sensoriales olfatorios en el epitelio de la roseta.

Los experimentos para determinar el paso del agua por el aparato olfatorio han demonstrado que ésta fluye por la cámara debido al movimiento de avance del pez, y que es probable que al abrir la boca aumente la entrada de agua en la cámara por efecto del saco accesorio.

Se ha llegado a la conclusión de que el barrilete tiene un órgano olfatorio factible de funcionar.

1 INTRODUCTION

The skipjack tuna, Katsuwonus pelamis (Linnaeus), has no precise morphological or histological description of its olfactory organ recorded in the literature. Burne (1909) provided a relatively limited, concise description of the general anatomy of the olfactory organs of a number of fishes, including Scomber scombrus. Kishinouye (1923) included a very brief and generalized account of the olfactory organ of several scombroids, including the Katsuwonidae.

The purposes of the present investigation are (1) to describe the morphology and histology of the skipjack olfactory organ, and (2) to determine the path of water through the olfactory apparatus and the mechanisms involved in the process.

2 MATERIALS AND METHODS

2.1 Field methods

The skipjack used for histological study were collected from the fishing sampan Buccaneer, of Honolulu, Hawaii.

In order to prevent autolysis the material was placed in a fixative within a few minutes after the fish had been caught. The procedure was to remove the forward part of the head just anterior to the eyes, split the excised section of the head sagittally on the median plane, and make two incisions into the olfactory chamber, along the upper edge of the lacrymal bone and between the external nares. The specimen was then immediately put in a fixative. The above technique permitted rapid penetration and produced satisfactory results for most tissue, but it was not rapid enough to preserve the delicate olfactory sensory hairs. To preserve the olfactory hairs the olfactory rosette was removed from the chamber and placed in 7 percent formalin in Ringer's solution immediately after the fish was landed. A number of fixatives were used. These were 10 percent formalin, 7 percent formalin in Ringer's solution, Bouin's fluid, Gilson's fluid and Zenker's fluid. In addition, olfactory epithelium placed in Ringer's solution immediately after removal from a live fish was stained lightly with methylene blue and examined for the presence of cilia by a method described by Hopkins (1926).

2.2 Laboratory methods

Tissue fixed in the formalin solution, Bouin's fluid, or Gilson's fluid could be left in the fixative for several weeks without being impaired in quality. Material fixed in Zenker's fluid was transferred after 12 hours, through 35 percent and 50 percent ethyl alcohol to 70 percent alcohol. If it remained in the fixative for longer than 12 hours the cells seemed to undergo excessive shrinkage. Mercuric crystals were removed from the Zenkerized sections by a 15-minute treatment with iodized alcohol.

Standard methods of clearing, imbedding, sectioning, and staining were followed, but some experimentation and modification were necessary to obtain satisfactory results.

Both ethyl alcohol and dioxane were used as dehydrating agents. Alcohol gave consistently good results, but a large proportion of tissue dehydrated with dioxane was too brittle for sectioning.

Cedarwood oil was the best clearing agent used. No hardening effect was observed, and the relatively slow infiltration of paraffin was accompanied by very little shrinkage. Both xylol and benzol had a hardening action and considerable shrinkage was observed with xylol during paraffin infiltration.

A medium grade of paraffin with a melting point of 56° C was used. Epithelial tissue, such as the rosette, was completely impregnated after 1.5 hours, whereas denser connective tissue required about 2.5 hours for complete infiltration.

All sections were cut at 6μ.

Heidenhain's hematoxylin and Harris' hematoxylin, counterstained with eosin, both gave satisfactory results. Heidenhain's hematoxylin stained better if the iron-alum mordant was allowed to act for 12-24 hours. Krichesky's modification of Mallory's triple stain, described in Jones (1950), and Van Gieson's connective tissue stain with Weigert's iron hematoxylin were used as differential stains.

3 MORPHOLOGY

Osteological terms in the following description are taken from Gregory (1933).

The external anatomy of the olfactory system fits into the general streamlining of the skipjack, offering little resistance to the flow of water past the head (Fig. 1). The anterior naris is a small circular opening, about 0.3 mm in diameter on a fish about 45 kg in weight and 72 cm in fork length. A mound of skin behind the anterior opening projects about 0.3 mm from the head surface, and in effect forms a hood which gives the external nostril an anteriorly directed aspect. The passage into the capsule from the anterior naris is roughly perpendicular to the surface of the head. The posterior naris, 1.7 cm behind the anterior naris, is an elongated vertical slit, 1.4 cm in length with its upper extremity slightly ventral to the anterior naris (Fig. 1). The slit-like opening is directed posteriorly, with its interior passage leading obliquely forward into the olfactory chamber. A posteriorly directed flexible lip of skin overlaps the slit and potentially serves as a one-way valve against ingress of water.

The right and left olfactory chambers, Fig. 2, lie in depressions of the ethmoid bone, bounded above by the nasal bones. On each side the chamber extends posteriorly from immediately caudal to the anterior process of the nasal bone, above the upper surface of the palatine bone, to the anterior rim of the orbit. Below the chamber and extending a little posterior to it there is an accessory sac or chamber. This accessory sac is bounded laterally by the lacrymal bone and extends posteriorly from the anterior margin of the lacrymal, parallel and mesial to its inner surface, to a point lateral and ventral to the palatine-pterygoid suture. The palatine bone and the buccal membrane delimit the sac mesially and ventrally. An elongate opening about 11 mm long and 4 mm wide between the palatine and lacrymal connects the accessory sac and olfactory chamber (Fig. 2). The entire length of the accessory sac lies above the maxillary bone, by which the sac is compressed when the mouth is closed and expanded when the mouth is opened.

An olfactory rosette (Fig. 2) is located directly beneath each anterior naris. Its axis, perpendicular to the head surface, is attached anteriorly to the inside lip of the narial opening. Olfactory leaves about 5 mm in length, with their plane surfaces perpendicular to the head surface, radiate posteriorly from the axis through an arc of about 180°. A few of the most dorsal leaves are beneath the nasal bone, but most of the rosette is under the fleshy roof of the olfactory chamber. The number of leaves varies between fishes and between capsules in a single specimen. In 38 rosettes the number ranged from 34-47 per rosette. The leaves form a pit-like indentation where they join the rosette axis just mesial to its juncture with the lip of the naris. Water passing into the anterior naris would be directed into this pit and would flow along the epithelial surfaces of the leaves to enter the olfactory chamber. The mesial borders of the rosette leaves are firmly attached to the membrane which lines the olfactory capsule and, according to Allison (1953), are complex folds of that tissue.

Numerous small nerve trunks leave the base of the rosettes and form larger trunks, the olfactory nerves, which pass through foramens in the ethmoid into the cranial cavity prior to their juncture with the olfactory bulbs. A trunk of the trigeminal nerve also passes through the ethmoid and apparently innervates the lining of the chamber, but no branches were found leading from the rosette proper. In vertebrates the profundus ophthalmic branch of the trigeminal nerves is known to supply fibers to the nasal area (Allison, 1953; Weichert, 1951).

The fleshy roof overlying the olfactory chamber extends from the dorsal border of the lacrymal to the lateral edge of the nasal, and from the anterior edge of the rosette to the posterior naris (Fig. 2). The area immediately overlying the rosette consists primarily of the dermis, but the tissue overlying the rest of the chamber consists of two elongate mounds which bulge inward from the outer dermis (Fig. 2). The upper mound extends from immediately posterior to the rosette to the posterior naris. The lower mound parallels the upper mound and extends to the posterior naris. Anteriorly the two mounds form a cavity into which the rosette fits. A narrow channel running between the mounds opens into the posterior naris. The lower mound is parallel to the antero-dorsal margin of the lacrymal and fits closely over the opening between the accessory sac and the olfactory chamber (Fig. 2).

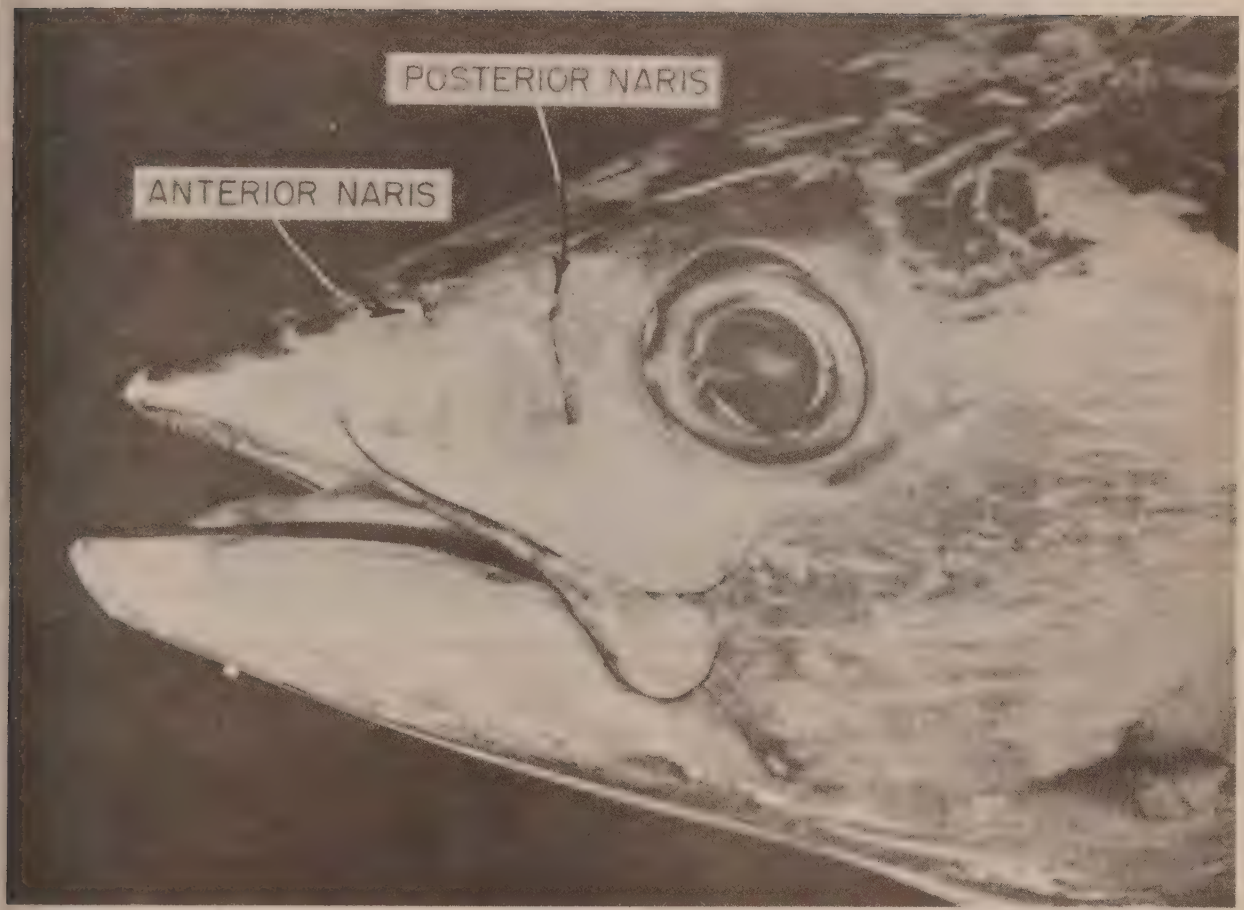
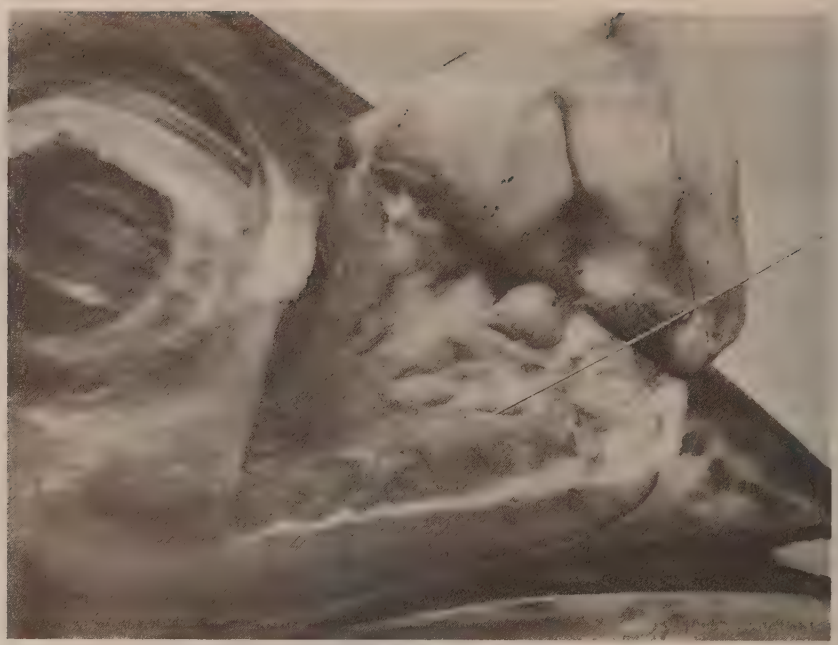


Fig. 1 Skipjack's external nares



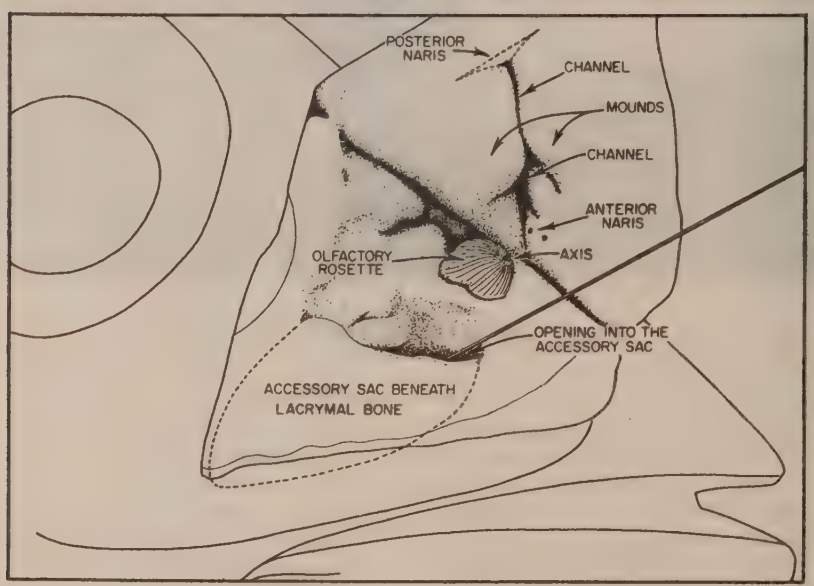


Fig. 2 Olfactory chamber

4 HISTOLOGY

The olfactory chamber and accessory sac are lined with mucous membrane. On the mesial wall of the chamber this lining consists of stratified squamous epithelium overlying a fatty stroma richly supplied with small blood vessels. The olfactory nerve runs from the rosette through this underlying stroma before passing through the ethmoid. The membrane lining the accessory sac is less fatty and not as highly vascularized as the membrane of the olfactory chamber. The two mound-like protuberances on the lateral walls of the chamber consist predominantly of white fibrous connective tissue. Chromatophores are scattered in the membrane lining the walls of the chamber but are not found on the membrane lining the accessory sac. The lip of the anterior naris is a continuation of the squamous epithelium of the dermis but is non-cornified.

The rosette axis consists mainly of a moderately loose, collagenous connective tissue (Fig. 3). The rosette leaves branching out from the axis are formed of an outer layer of pseudostratified epithelium and an inner collagenous stroma similar to the stroma of the axis. Occasional scattered groups of chromatophores occur on the distal margins of the leaves. The epithelium on the proximal portion of the leaves, about three-quarters of the distance from the axis to the extremity of the leaf, is a typical pseudostratified olfactory epithelium about 50μ thick (Fig. 3).

The olfactory epithelium of the leaves is composed of three distinct cell types: supporting cells, basal cells, and olfactory sensory cells. The supporting or sustentacular cells, Fig. 4, are columnar and non-ciliated. Their basal processes extend down into the supporting reticulum underlying the epithelium and their free borders are exposed to the chamber. Oval nuclei of the sustentacular cells are located about midway between the surface and base of the epithelium. The basal cells are in close conjunction with the basal reticulum (Fig. 3). Their nuclei are small and stain darkly. No distinct basement membrane is apparent. Interspersed between supporting cells are a smaller number of olfactory sensory cells (Fig. 4). These are spindle-shaped cells with a round nucleus in the basal portion. The distal part of the cell body reaches nearly to the surface. A slender process (the dendrite) passes through the epithelial surface and continues as the so-called olfactory hair into the olfactory chamber. In the preparations examined a single hair extends 8-15μ from each cell. Much finer processes (the axons) run from the basal portions of the olfactory cells. They pass between the supporting cells and enter the basal reticulum, but could not be traced any farther.

Axons from the sensory olfactory cells apparently combine to form the nerve fasciculi present in the central stroma of the rosette leaves (Fig. 3). Fasciculi are located in the leaves, and around the periphery of the axis. They extend parallel to the axis, and the individual bundles become progressively larger towards the distal portions of the leaf. These fasciculi extend into the underlying stroma and form the small nerves which make up the olfactory nerve. No fasciculi are found in the outermost portion of the leaves, and the epithelium covering that area is somewhat thicker than the olfactory epithelium of the more proximal leaf surfaces (Fig. 3). No olfactory hairs are present beyond the area in which nerve fasciculi occur. The supporting stroma of the rosette leaves and axis is supplied with numerous venules, arterioles, and capillaries.

5 EXPERIMENTS TO DETERMINE WATER FLOW THROUGH THE OLFACTORY CHAMBER

The anatomy of the skipjack olfactory organ suggests that the accessory sac may pump water in and out of the olfactory chamber. A series of experiments was conducted to determine whether compression of the sac by jaw movements does increase water flow into the chamber, and also to determine whether water enters the chamber of a fish swimming at average speeds without jaw movements. The experiments were conducted using heads of fresh 45 kg skipjack obtained from the fish market.

5.1 Methods

Prior to each experiment the olfactory chamber and the nasal openings were cleaned of blood and mucous by gently inserting a blunt hypodermic needle into the posterior naris and injecting water into the chamber until it squirted from the anterior naris. The heads were then placed in standing or flowing water dyed with

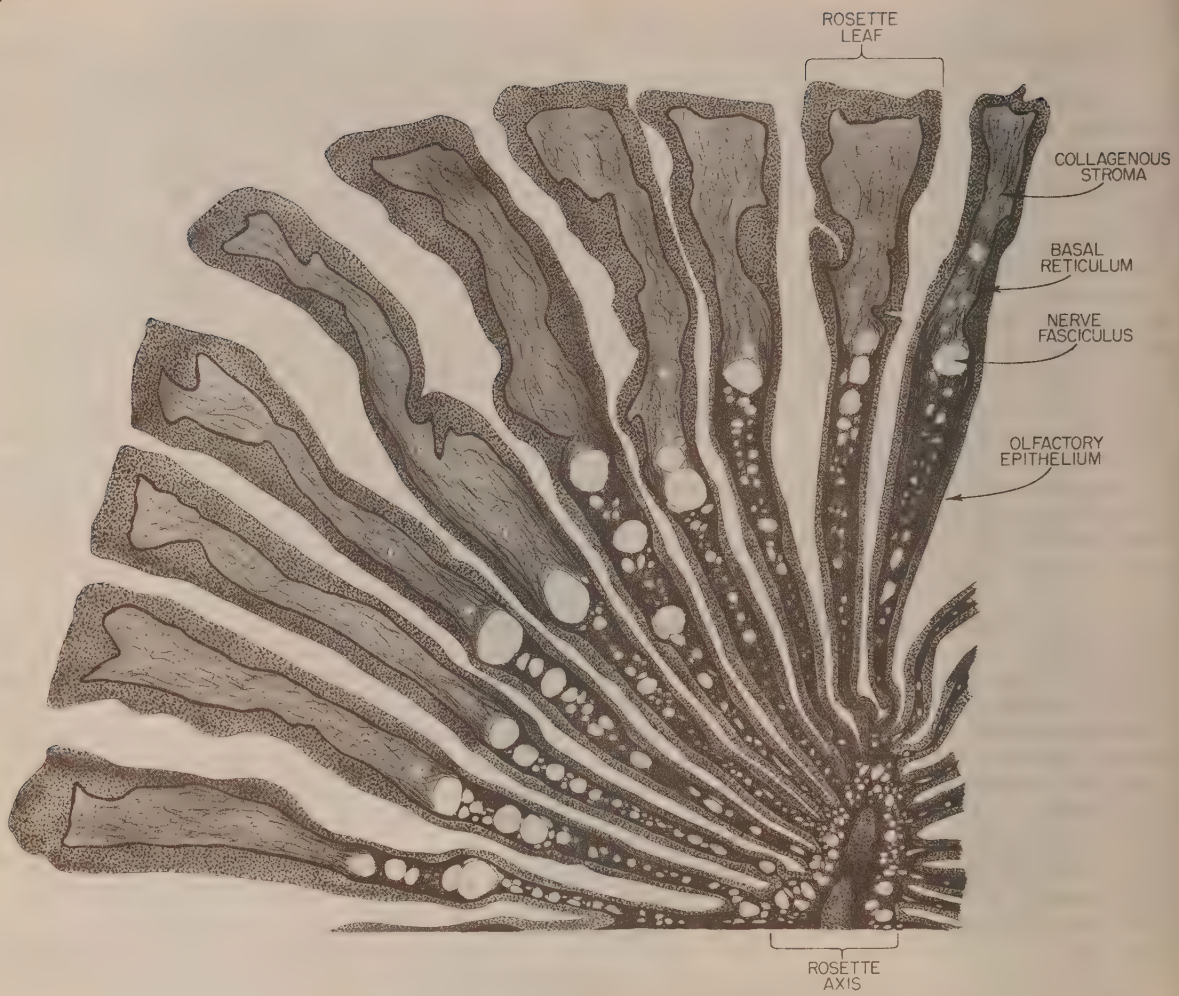


Fig. 3 Cross section of a segment of the olfactory rosette and axis. 150 X

Fig. 4 Section of a skipjack's olfactory epithelium, showing the supporting cells and the olfactory cells with their associated sensory hairs. 950 X

methylene blue. The amount of dye entering the olfactory chamber, determined qualitatively by inspection, was used as a measure of the quantity of water entering in the different treatments. The current velocity used in the experiments (300 cm per second) corresponds to average swimming speeds observed in feeding skipjack at sea.[1/] The influence of jaw movements was measured both in the standing and flowing water tests. Jaws were either held stationary or worked up and down by the experimenter.

5.2 Results

Tests on 17 fish held in flowing water indicated that the same amount of water entered the chamber when the jaws were worked or held stationary. Tests on 8 additional fish heads in standing water indicated that much more water entered when the jaws were worked than when they were held stationary.

In another experiment the olfactory chamber was filled with dye and it was observed that in still water small spurts of dye were ejected from the posterior naris when the jaws were closing, whereas almost no dye came from the anterior naris. In flowing water dye was ejected from the posterior naris when the jaws were worked, but none was ejected from the anterior naris.

A final test was made to determine whether the flap on the posterior naris acted as a one-way valve allowing water to exit but not enter. Heads were held in a current and either the posterior or anterior naris was occluded. Water entered the chamber when the posterior naris was occluded, but did not enter when only the anterior naris was occluded.

6 DISCUSSION

The anatomy of the olfactory apparatus of the skipjack is typical in general structure of fishes possessing accessory sacs. According to Burne (1909), the position of the olfactory chamber relative to the bones of the head and the location of the rosette directly below the anterior naris are almost universal. The relationships between the accessory sac and the associated maxillary bone, the mound-like structure on the lateral wall of the chamber, and the valved posterior naris are of particular interest in the skipjack. The ventral mound fits closely over the opening between olfactory chamber and accessory sac and apparently serves as a valve between them. Opening the jaws depresses the maxillary in a manner that increases the volume of the accessory sac and closing the jaws has the opposite effect. This system could be expected to function as a bellows-like pump. The structure of the posterior naris resembles a one-way valve, permitting little or no entrance of water.

Skipjack observed in the tanks at the Bureau of Commercial Fisheries Biological Laboratory, Honolulu, occasionally open and close their mouths with a snapping movement. This is not necessarily feeding behavior, as the movements are made even when the fish are not eating, nor is it probable that it can be considered mating behavior, as the fish are sexually immature. Skipjack normally swim with their mouths slightly agape (Nakamura, in press), permitting a free flow of water over the gills. Hall (1930) showed that in the mackerel, Scomber scombrus, the O_2 saturation in the blood decreased from 85 percent in a free-swimming fish to 11 percent in a closely confined fish. The respiratory current is apparently developed through forward progression, and it appears unlikely that any gill or jaw movements are required for respiration.

On this basis we feel that these snapping movements may be the equivalent of a sniff, which draws additional water into the olfactory chamber. It is possible that the movements are made more frequently at slow swimming speeds when a relatively small volume of water is passing through the chamber.

It is interesting to compare the olfactory sensory hairs of the skipjack with those demonstrated by previous workers. Jagodowski (1901) observed that sensory hairs may be twice as long as the olfactory epithelial cells in the pike, Esox lucius. In the frog, Rana, 4-6 hairs extended 150μ or more beyond the epithelium (Hopkins, 1926). In the scup, Stenotomus chrysops, Hopkins found scattered olfactory

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1/ These speeds were calculated in our laboratory from underwater motion pictures taken of feeding skipjack from the viewing chamber of the research vessel Charles H. Gilbert.

hairs 20-30μ long, and there appeared to be more than one hair to a cell.

Sensory hairs in the skipjack are seldom more than 10μ long, and apparently there is only one to a cell. Considerable difficulty was encountered in demonstrating the olfactory hairs, and the hairs which were demonstrated quite often had a truncated appearance. Parts of these delicate structures may have been destroyed during processing of the tissue. Further perfection of technique may demonstrate the existence of longer hairs, and possibly of more than one to a cell.

Van Weel (1952) observed that little tunny (Euthynnus yaito) and yellowfin tuna (Neothunnus macropterus) held in captivity responded to clear extracts of tuna flesh. He concluded that a chemical sense is present, but could not say whether it was a sense of smell or taste. Tester et al. (1954) continued these experiments and obtained very positive responses from little tunny (Euthynnus affinis). They felt that there was no doubt the response was through the fish's sense of either smell or taste.

The results of this study show that skipjack possess a potentially functional olfactory apparatus, and that the sense of smell could account for at least part of any chemoreceptive abilities of this species.

On the basis of the anatomy and histology of the skipjack's olfactory apparatus and the results of the experiments, the conclusions are that a continuous stream of water flows slowly through the olfactory capsules of a swimming skipjack, entering through the anterior nares and exiting through the posterior nares, and that an additional increment of water is probably drawn in via the anterior nares when the mouth is opened and is ejected via the posterior nares when the mouth is closed, especially when the fish is swimming at slow speeds.

REFERENCES

Allison, A.C., The morphology of the olfactory system in the vertebrates. Biol.Rev., 1953 38(2):195-244

Burne, R.H., The anatomy of the olfactory organ of teleostean fishes. Proc.zool.Soc. 1909 Lond., 2:610-62

Gregory, W.K., Fish skulls: a study of the evolution of natural mechanisms. Trans. 1933 Amer.phil.Soc., 23(2):75-481

Hall, F.G., The ability of the common mackerel and certain other marine fishes to 1930 remove dissolved oxygen from sea water. Amer.J.Physiol., 93(2):417-21

Hopkins, A.E., The olfactory receptors in vertebrates. J.comp.Neurol., 41:253-61 1926

Jagodowski, K.P., Zur Frage nach der Endigung des Geruchsnerven bei den 1901 Knochenfischen. Anat.Anz., 19:257-67

Jones, R.M., McClung's handbook of microscopical technique for workers in animal and 1950 plant tissues. Transl. Paul B. Hoeber, New York, 790 p.

Kishinouye, K., Contributions to the comparative study of the so-called scombroid fishes. 1923 J.Coll.Agric.Tokyo, 8(3):293-475

Nakamura, E.L., Observations on the behavior of skipjack tuna (Euthynnus pelamis) in captivity

Tester, A.L., P.B. van Weel and J.J. Naughton, Reaction of tuna to stimuli, 1952-53 1954 Part 1. Spec.sci.Rep.U.S.Fish Wildl.Serv.(130)

van Weel, P.B., Reaction of tunas and other fishes to stimuli. Part II. Spec.sci.Rep. 1952 U.S. Fish Wildl.Serv.(91)

Weichert, C.K., Anatomy of the chordates. McGraw-Hill, New York, 921 p. 1951

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XI. United States Research Report, 1962

by Herbert W. Graham

Analysis of commercial landings statistics has been greatly facilitated by the installation of a data processing unit at the Woods Hole Laboratory of the Bureau of Commercial Fisheries. Analyses are now being made on a back log of data relating to species previously neglected and to many aspects of the major species which previously could not be treated because of the enormity of the mass of data.

Surveys in Subareas 4 and 5 were made using primarily the Bureau's research vessel DELAWARE and to a lesser extent charter of small fishing vessels. Nine cruises, averaging two weeks each, were made by the DELAWARE in groundfish research, and two in herring research.

HADDOCK (Melanogrammus aeglefinus (L.))

The Fishery. Georges Bank is the main source of haddock to the US fishery. During the period 1957-61 about 75 percent of the landings came from Georges Bank (Division 5Z), 10 percent from the Gulf of Maine (Division 5Y), and 15 percent from Browns Bank (Division 4X). Average landings from Georges Bank in this period were 7 million pounds. This was 10 percent below the 1931-60 average of 89 million pounds. In 1962, US landings from Georges Bank were 9.3 million pounds and from all areas 15 million pounds.

The comparatively high figure for Georges Bank in 1962 was probably due to an increased abundance over levels of the few years preceding. The mean catch per day for Georges Bank for the period 1931-60 was 13,000 pounds. For the period 1957-61 it had dropped to about 10,000 pounds. In 1961 the index was back up to 13,000 pounds per day and the estimated figure for 1962 is about the same. The fact that larger fish were landed in 1962 may indicate some change in fishing habit in reference to change in size composition of the populations.

These recent fluctuations in abundance have been due to variations in strengths of year classes (Fig.1). The lower figures for the period 1957-60 were due to a succession of weak or moderate year classes. The relatively strong 1958 and 1959 year classes account for the increased abundance in 1961 and 1962.

Abundance is expected to remain high until the summer of 1963 when scrod abundance probably will decline because of the apparently weak incoming 1960 year class. Catches of young-of-the-year haddock in the 1961 and 1962 fall surveys suggest that the broods for these years are also weak.

Canadian - United States 4X Program. This program was started in 1956 and included the exchange of catch-effort statistics and size-age samples between the US and Canada, with the US assuming primary responsibility for analyzing commercial

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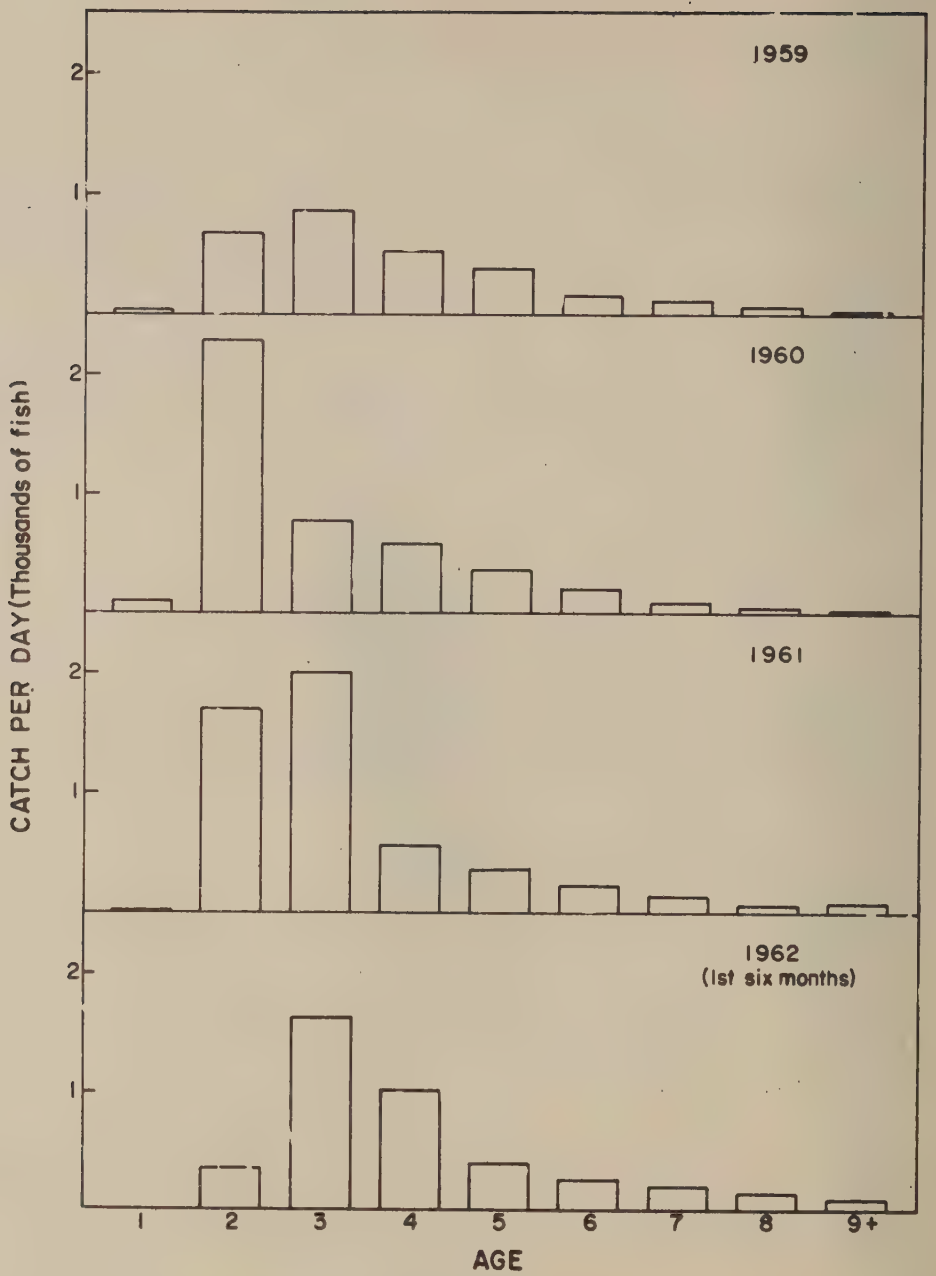
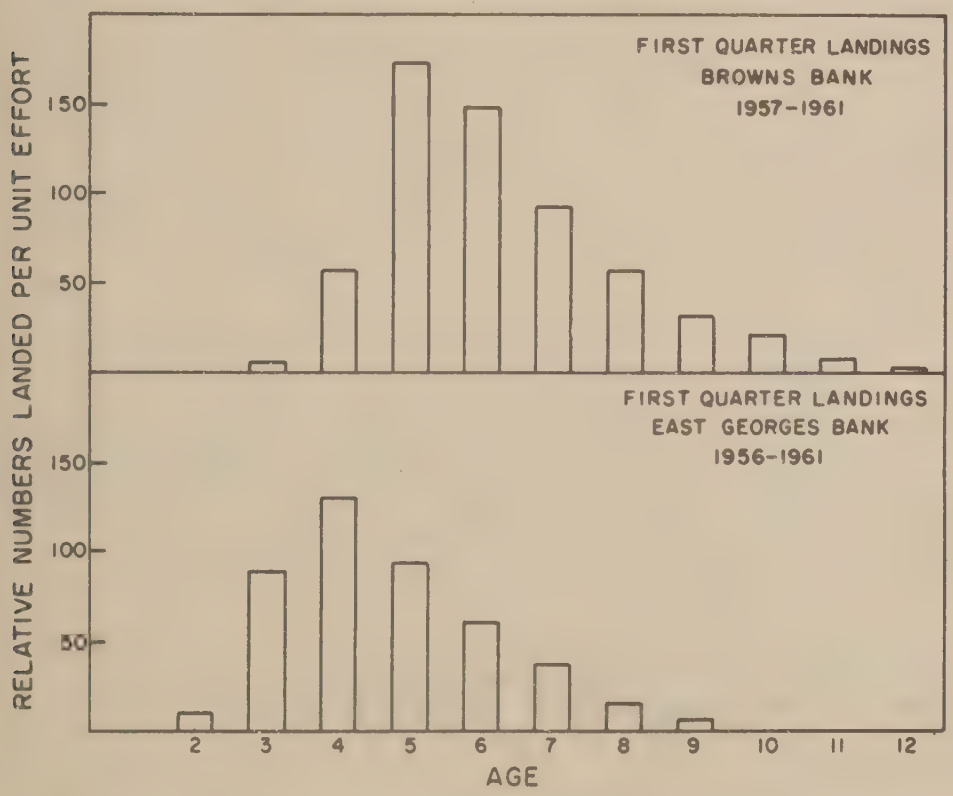


Fig. 1. Georges Bank Haddock. Catch per day (thousands of fish) at each age. 1959-1962.

ings. During the initial stages of this program a backlog of otoliths accumulated. se have now been read and a preliminary analysis of all the data has been com- ed. A preliminary report has been discussed by Canadian and US biologists at a t meeting and some of the findings are presented here.

The average age of haddock in the Browns Bank landings is higher than for rges Bank. About 90 percent (by number) of first quarter landings from Browns k is composed of ages 4-8, whereas the same proportion of first quarter Georges k landings is composed of ages 3-7 (Fig.2)



. 2. Age composition of haddock landings from Georges Bank and Browns Bank.

Catch curves based on first quarter age compositions show that recruitment into spring fishery is completed between ages 4 and 5 on Georges Bank, and between ages d 6 on Browns Bank (Fig.3). After full availability to the gear, the relative abund- ne of comparable ages in the spring appears to be substantially higher on Browns Bank n on Georges Bank. The estimated total annual mortality rate for age 6 and older is ercent for Browns Bank as compared to 50 percent for Georges Bank.

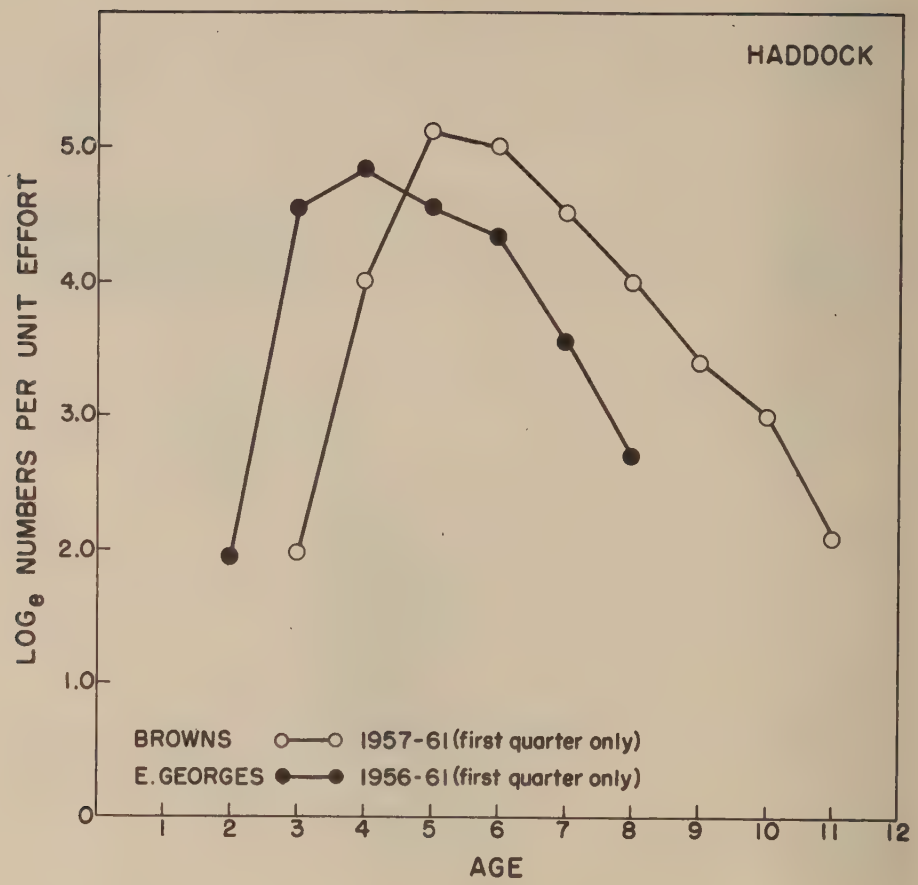


Fig. 3. Catch curves for haddock from Georges Bank and Browns Bank.

Georges Bank haddock grow faster than Browns Bank haddock and the average difference in length increases with age (Fig. 4).

COD (Gadus morhua L.)

The Fishery (Table 1). The 1961 landings which amounted to 32 million pounds represented a 10-year high, exceeded only by the 36 million pounds landed in 1951 and the preliminary estimate for 1962 is somewhat higher than the figures for 1961.

Previous peak landings were recorded in 1958 and again in 1959 when the trawlers brought in more cod to compensate for the scarcity of haddock at that time. When haddock again became abundant, as in 1960, cod landings decreased slightly. It is interesting to note, however, that in 1961, when scrod haddock landings were the heaviest they had been in 5 years, cod landings also increased. This may have been due to an increased market demand for food fish of all species.

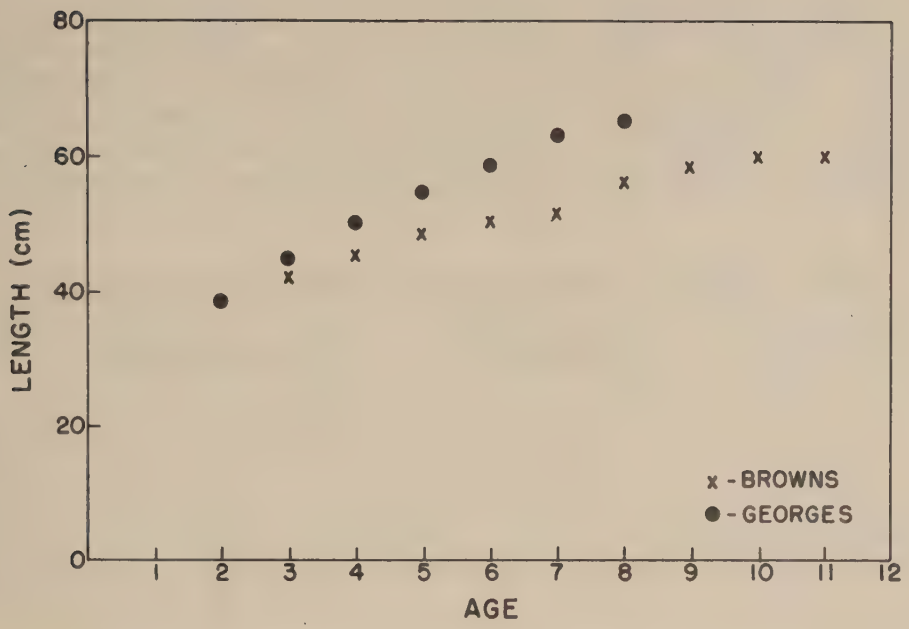


Fig. 4. Mean length at each age in commercial haddock landings from Georges Bank and Browns Bank.

Studies of commercial landings and research vessel catches, and our knowledge of the biology of the species, suggest that cod will be abundant on the traditional New England fishing grounds in 1963. Our research in the coming year will be directed in part to monitoring the commercial landings, particularly the length and age composition of the catch.

Table 1. Trends in the cod fishery (New England ports, gutted weight in 000's pounds).

Year	Landings
1957	24,177
1958	29,857
1959	30,559
1960	26,117
1961	32,442
1962 (estimated)	32,713

SILVER HAKE (Merluccius bilinearis (Mitchill))

The Fishery. Landings of silver hake have shown a steady decline since 1959 due first to a decline in the industrial fishery and then to a decrease in landings for food (Table II). A good index of abundance for this species has not yet been developed but there is no reason to believe that abundance has changed markedly over the last few years.

Research. Silver hake undergoes a pronounced seasonal migration, retreating to deeper offshore waters in the winter which results in extreme variations in availability. The fishery accordingly is markedly seasonal. More information is needed on the winter distribution of the species and on the relation of this species to depth, temperature, and other ecological factors. This kind of information is now emerging from an analysis of past survey cruises which are conducted mainly in summer and fall but will not be adequate until the new year round program of groundfish surveys is initiated.

Table II. Trends in the New England silver hake fishery (millions of pounds).

Year	For Food	For Industrial	For Animal Food	Total
1957	117	38	16	171
1958	107	23	17	147
1959	110	26	20	156
1960	103	5	20	128
1961	84	7	10	101
1962	60	7	16	83

FLOUNDER

The Fishery. The high level of New England flounder landings in recent years has been due largely to increases in yellowtail flounder abundance (Table III). Of particular importance to the high yellowtail landings for 1962 were contributions from the strong year classes of 1958 and 1959. Landings of fluke dropped sharply in 1962. (Fluke length and age data now available are insufficient to show the reason for this decline.)

Table III. Flounder landings (millions of pounds).

Species	1958	1959	1960	1961	1962-Preliminary
Yellowtail flounder (Limanda ferruginea)	32.8	29.0	29.9	37.1	53.1
Blackback (Pseudopleuronectes americanus)	14.1	14.3	17.1	17.5	16.3
Fluke (Paralichthys dentatus)	5.5	5.5	6.7	6.3	4.2
Dab (Hippoglossoides platessoides)	3.0	3.1	3.0	3.5	4.0
Graysole (Glyptocephalus cynoglossus)	3.1	2.9	3.1	2.6	2.2
Total	58.1	54.8	59.8	67.0	79.8

Yellowtail fishing effort and relative abundance, as shown by landings per day he three New England grounds, was calculated from fishing trip weighout sche- s for the port of New Bedford for 1943-61. Fluctuations in landings were found to rgely related to abundance changes. Shifts in fishing effort generally followed the ges in abundance. Relative abundance was highest from Georges Bank, an off- e ground, and lowest from the Cape Cod ground, which is inshore. Trends in dance were similar on all three grounds, suggesting that factors affecting year s strength operated on all grounds simultaneously.

Tagging Experiments. Of the 4,960 yellowtail flounder tagged in 1955, 1957, 1959, 1020 tagged fish representing 20.6 percent of those released, were recap- d. Analysis of the returns show a definite seasonal pattern of movement which re- ed in each of the three years. There is an easterly migration in the spring and mmer and a westerly return in the fall and winter.

The high abundance of yellowtail flounder in 1962 was due to the presence of e strong year-classes: 1958, 1959 and 1960. These year-classes will continue to port the fishery in 1963 so this year should also be a good one for the yellowtail sery.

FISH (Sebastes marinus)

The Fishery. Judged from preliminary catch data, the 1962 United States red- s landings will total approximately 122 million pounds, the lowest annual total since 4 (Fig.5). This represents a continuation of the steady decline in United States red- s landings since 1951, to a level of about half the average annual landings for 1948- the peak period in the fishery.

Abundance Studies in the Gulf of Maine. United States landings from the Gulf of ne have declined steadily since the peak year of 1941 (Fig.6). Landings and fishing rt data for the entire Gulf of Maine do not show evidence of replenishment of the red- s stocks as would be expected to result from an extended period of diminished fishing rt following the initial reduction of the accumulated fish stocks. Detailed studies of data from smaller areas within the Gulf were undertaken to determine the effect of vy exploitation on small, isolated redfish stocks that were fished heavily in the early rs of the fishery, and then received several years of light fishing intensity (Fig.7).

Data from US Statistical Subarea XXII F (groundfish unit area F of ICNAF ision 5Y) are representative of trends in other areas in the Gulf (Fig.8). The fishery an there in 1936, rose rapidly to a peak of 70 million pounds by 1941, and declined kly to less than 21 million pounds by 1949. Landings from that area have fluctuated veen 12 and 25 million pounds each year since that time.

Growth of Tagged Fish. A tagging experiment is currently in progress at East- t, Maine, on the redfish stock that occurs there. Results during the past year

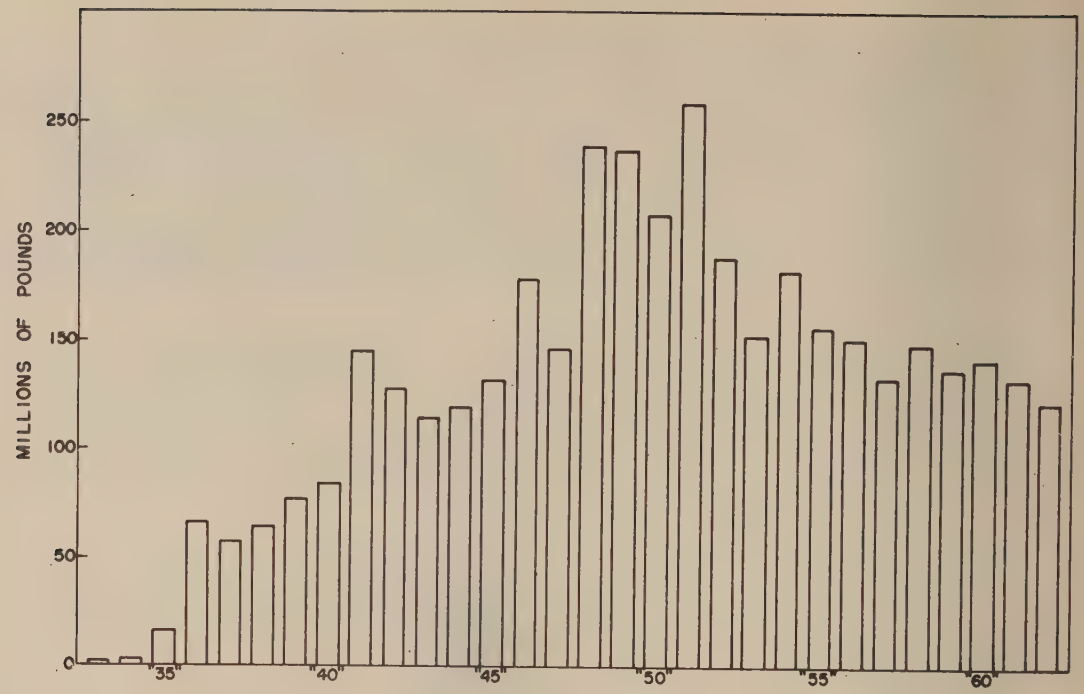


Fig. 5. United States Redfish Landings - 1933 - 1962.

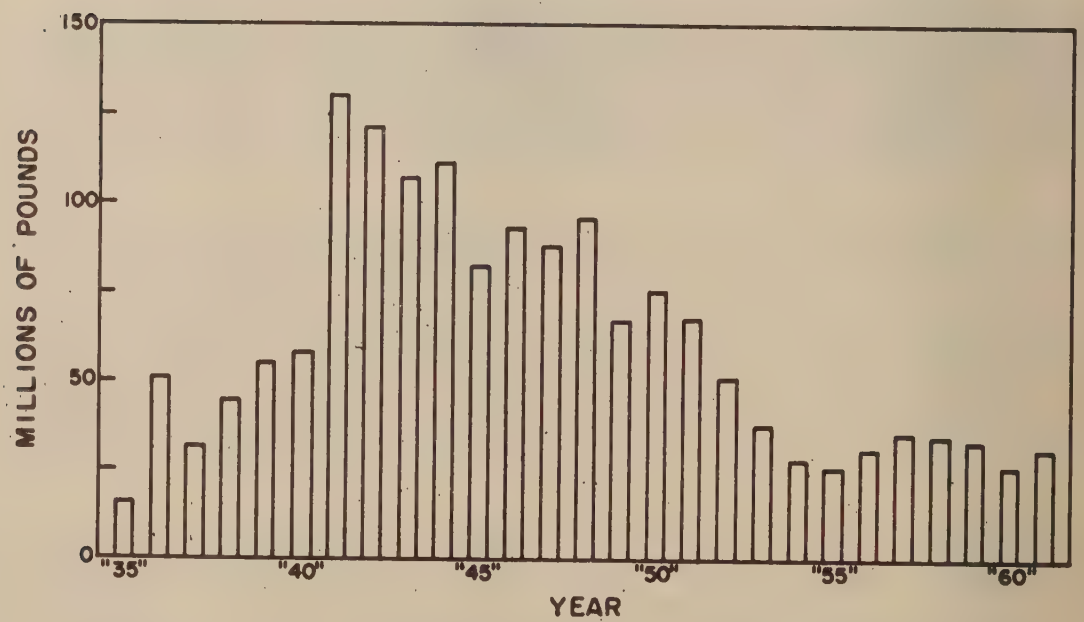


Fig. 6. Trends in Redfish fisheries - Gulf of Maine landings.

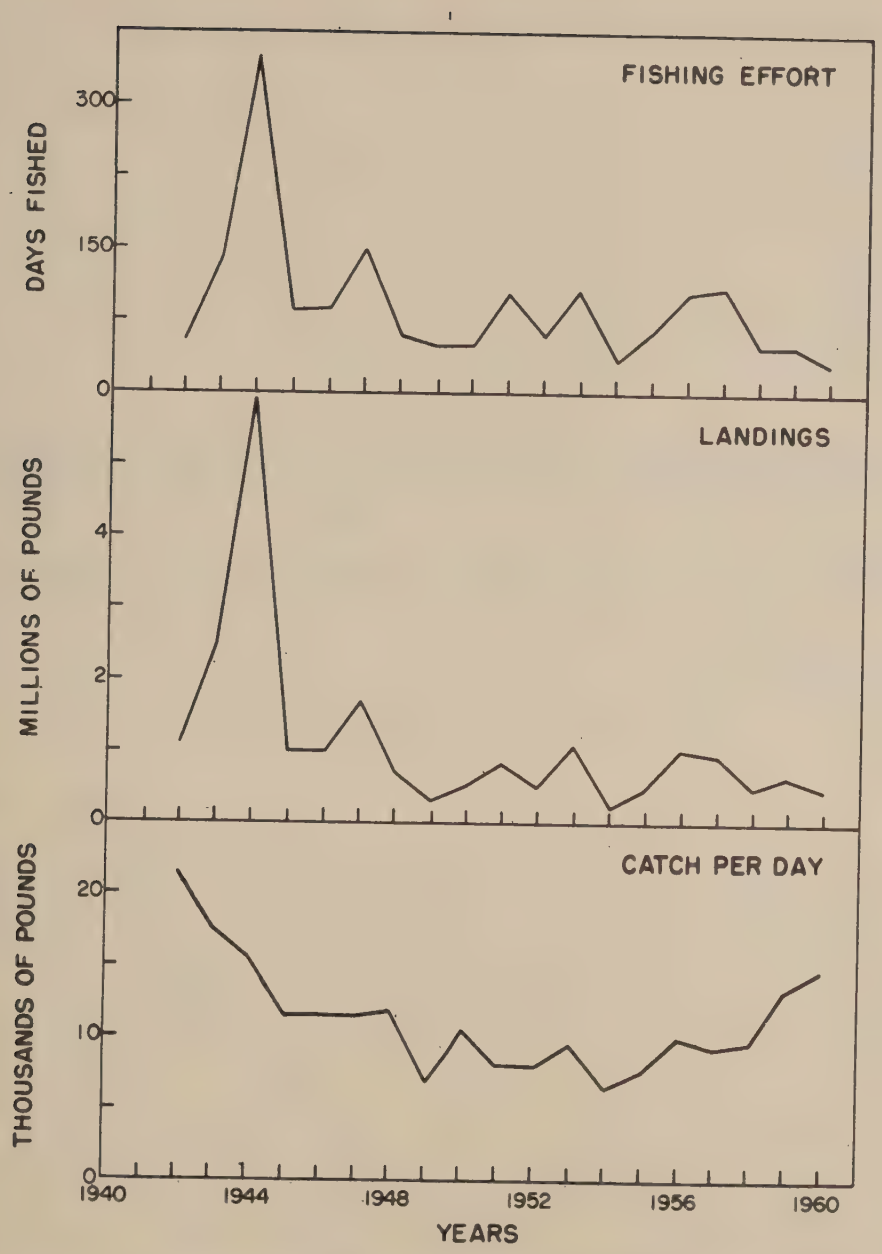


Fig. 7. Redfish catch and effort data for small interview area (42-68 B,C,D-1) of U.S. statistical area XXII F (groundfish unit area F of ICNAF Division 5Y) in central Gulf of Maine, 1942-1960.

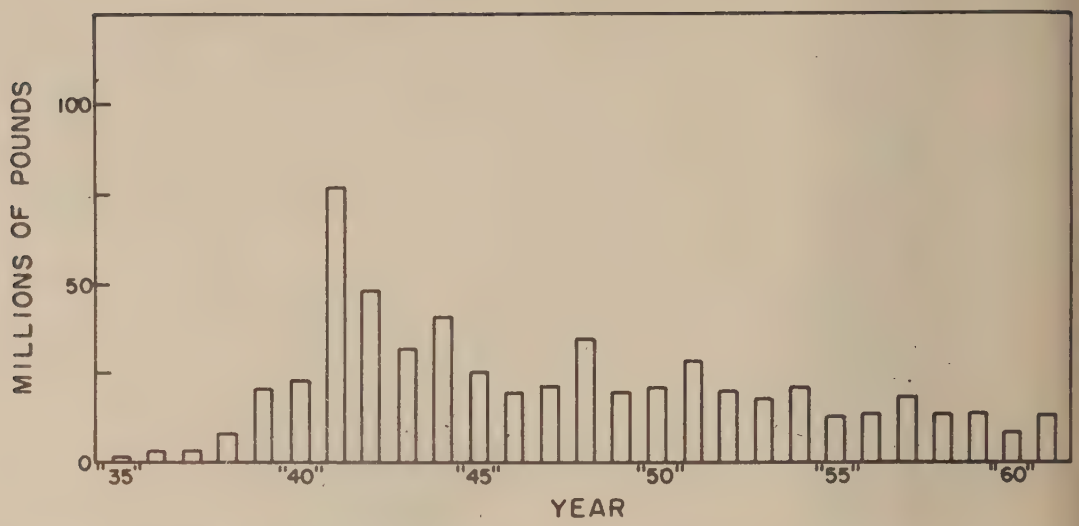


Fig. 8. Trends in Redfish fisheries - landings from U.S. statistical subarea XXII-F (groundfish unit area F of ICNAF Division 5Y).

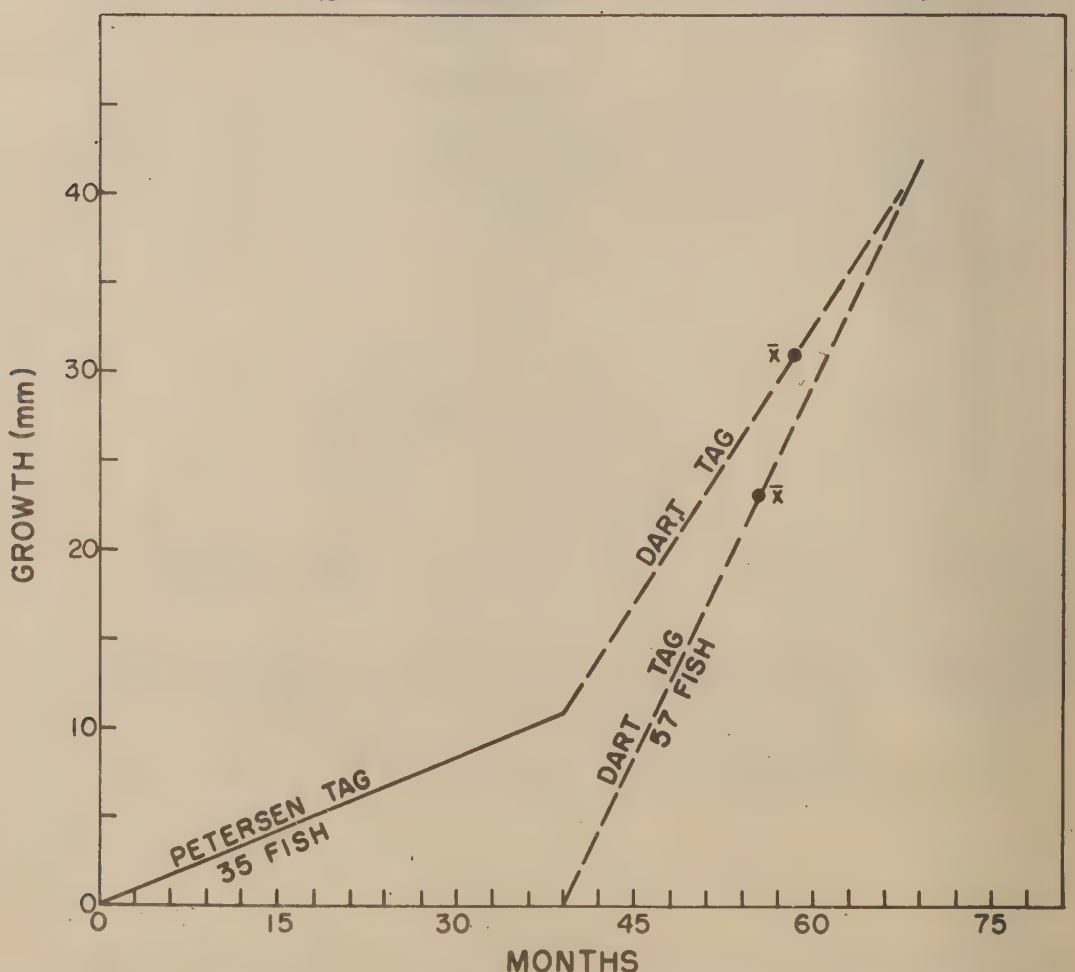


Fig. 9. Comparative growth rates of redfish tagged with two types of tags.

ve demonstrated dramatically the effect that different types of tags can have on the growth rate of tagged fish.

Earlier experiments had shown the growth rate of fish to be reduced to about 1 mm per year when they were first tagged with Petersen disc tags on the opercle. After two or three years of living with the opercle discs, the growth rate slowly increased toward the normal growth rate of the untagged fish. In the present work, we were able to remove Petersen disc tags from fish that had carried them for years and replace them with small plastic dart tags placed in the flesh of the dorsum. The recapture of a large number of these fish has shown them to be growing at the same rate as fish tagged for the first time with dart tags (Fig.9), and very close to the rate of growth of the untagged fish.

Thirty-five fish tagged initially with Petersen discs on the opercle grew an average of 11 mm in 39 months. When the tags were removed and plastic dart-spaghetti tags were inserted in the flesh of the dorsum, growth rate increased to an average of 20 mm in 19 months. The higher growth rate approached that of a group of 5 fish tagged with dart tags from the outset.

In this instance it would appear that the influence of the tag has been primarily caused by the position of attachment rather than any special attribute of the tag. The Petersen tag clearly inhibits growth, whereas the dart tag does not.

GROUNDFISH ECOLOGY

This program depends largely upon surveys conducted by research vessels operating throughout the area of interest through all seasons of the year for a number of years. Analysis of the accumulated data is not a simple task. For example, it has been found that comparisons of abundance of young of the year haddock cannot be made between years without taking into consideration the relative number of tows made at night and in the daytime since there appears to be a diurnal difference in availability of these fish on the bottom.

Table IV shows a comparison of abundance indices for day and night tows for haddock of different ages. It is evident that haddock under 2 years of age are more available to an otter trawl in the night time while haddock over 2 years of age are more available during daylight hours. The latter observation is known to the commercial fisherman.

Further investigation of the ecology of groundfish will undoubtedly reveal other environmental factors which must be taken into consideration in refining our estimates of abundance which are based on comparative data.

Table IV. Comparison of day and night catches of haddock. Research vessel to during September, 1953, and 1955, November, 1956, and September October, 1958.

		Day (0730-1629)			Night (1930-0429)		
		Number of Tows	Number of Fish	C/T	Number of Tows	Number of Fish	C/
Age Group 0	1953	35	30	0.9	24	32	1.
	1955	46	218	4.7	53	732	13.
	1956	34	72	2.1	37	58	1.
	1958	46	264	5.7	50	1216	24.
	Total	161	584	3.6	164	2038	12.
Age Group I	1953	38	33	0.9	24	2	0.1
	1955	42	45	1.1	54	349	6.8
	1956	35	74	2.1	37	48	1.3
	1958	46	286	6.2	50	548	11.0
	Total	161	438	2.7	162	947	5.8
Age Groups II and greater	1953	28	33	1.2	24	17	0.7
	1955	42	466	11.0	51	256	5.0
	1956	35	285	8.1	37	212	5.7
	1958	46	958	20.8	50	732	14.6
	Total	161	1753	10.9	162	1217	7.5

POPULATION DYNAMICS

The Woods Hole Laboratory has recently installed an automatic data proce ing unit which has greatly increased the Laboratory's ability to analyse the accum lation of back data as well as the voluminous quantity of current data which flows from the fishing ports.

In our population dynamics studies emphasis has been placed on developing methods for computing indices of abundance and effort, for estimating size and ag compositions of stocks; and in investigating mathematical models to which these variables may be applied to describe the effects of fishing.

Abundance indices. A proper, standard measure of catch-per-unit of fishi effort is needed to provide a relative index of abundance of commercial stocks, an to provide a means of measuring total effective fishing intensity. Our investigatio depend quite critically upon this index. We are, therefore, devoting time to study and further development of such indices for the various species of commercial importance.

Of particular concern in our mixed fishery is the problem of species direct fishing effort. Because of differential temporal and spatial variations in distribut

of the various species, the fisherman can direct, to some degree, his efforts so that the probability of catching one species or another is substantially increased. A common procedure has been to use, for calculating relative abundance of a given species, only those trips for which the amount landed is greater than some arbitrarily chosen proportion of the total. The proportion of the catch made up of a species is related to the abundance of the species itself, however, and there is a definite upward bias introduced which is particularly important when the range of abundance experienced is great. An illustration of this effect is provided by comparing the landings-per-days-fished of silver hake by medium-sized otter trawlers landing in Gloucester, 1960, as estimated from (A) all trips and (B) those trips in which silver hake were greater than 50 percent of the total (Fig. 10). The A index is generally lower and indicates a sharper seasonal index of what we purport to measure; the magnitude of the stock at the time and in the area concerned.

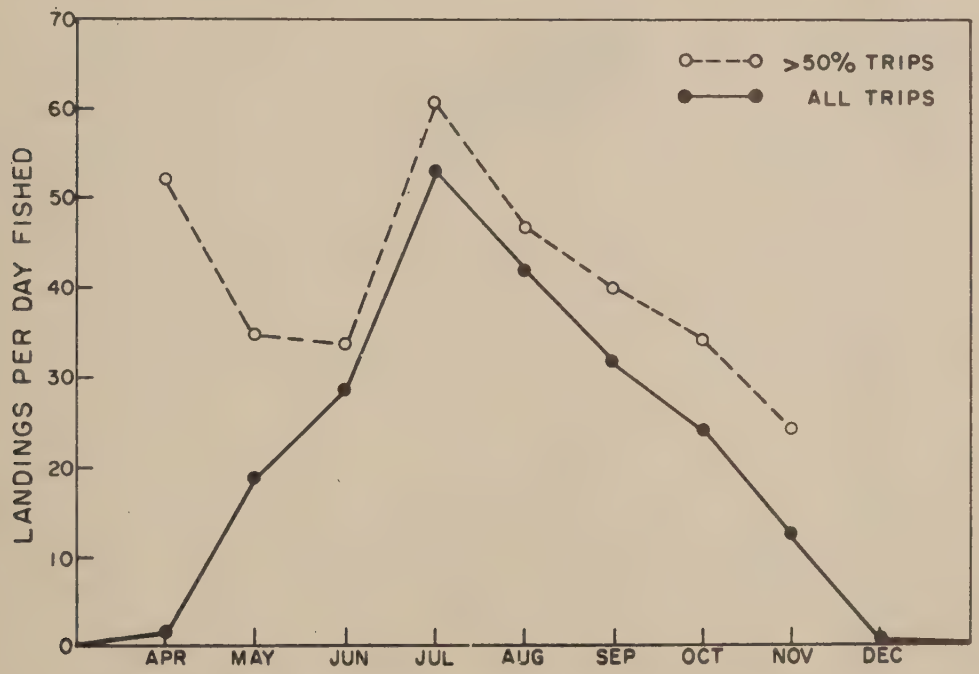


Fig. 10. Silver Hake Gloucester OTM 1960.

Mesh Assessment. We have continued to study the effects on yield of changing the size of mesh in cod ends of trawl nets. This work is co-ordinated by the mesh assessment working group of ICNAF. Most of the results of these studies are summarized in the "Report of Working Group of Scientists on Fishery Assessment in Relation to Regulation Problems" published this year by ICNAF as a supplement to the Annual Proceedings, Volume 11, and will not be repeated here. The main conclusion is that in most instances very moderate increases (on the order of 5 percent) in yield-per-recruit would be obtained by increasing mesh size beyond that now in use. A rather more important aspect is the effects on yield of increasing fishing intensity being experienced in Northwest Atlantic waters, and the working group is now emphasizing studies of this.

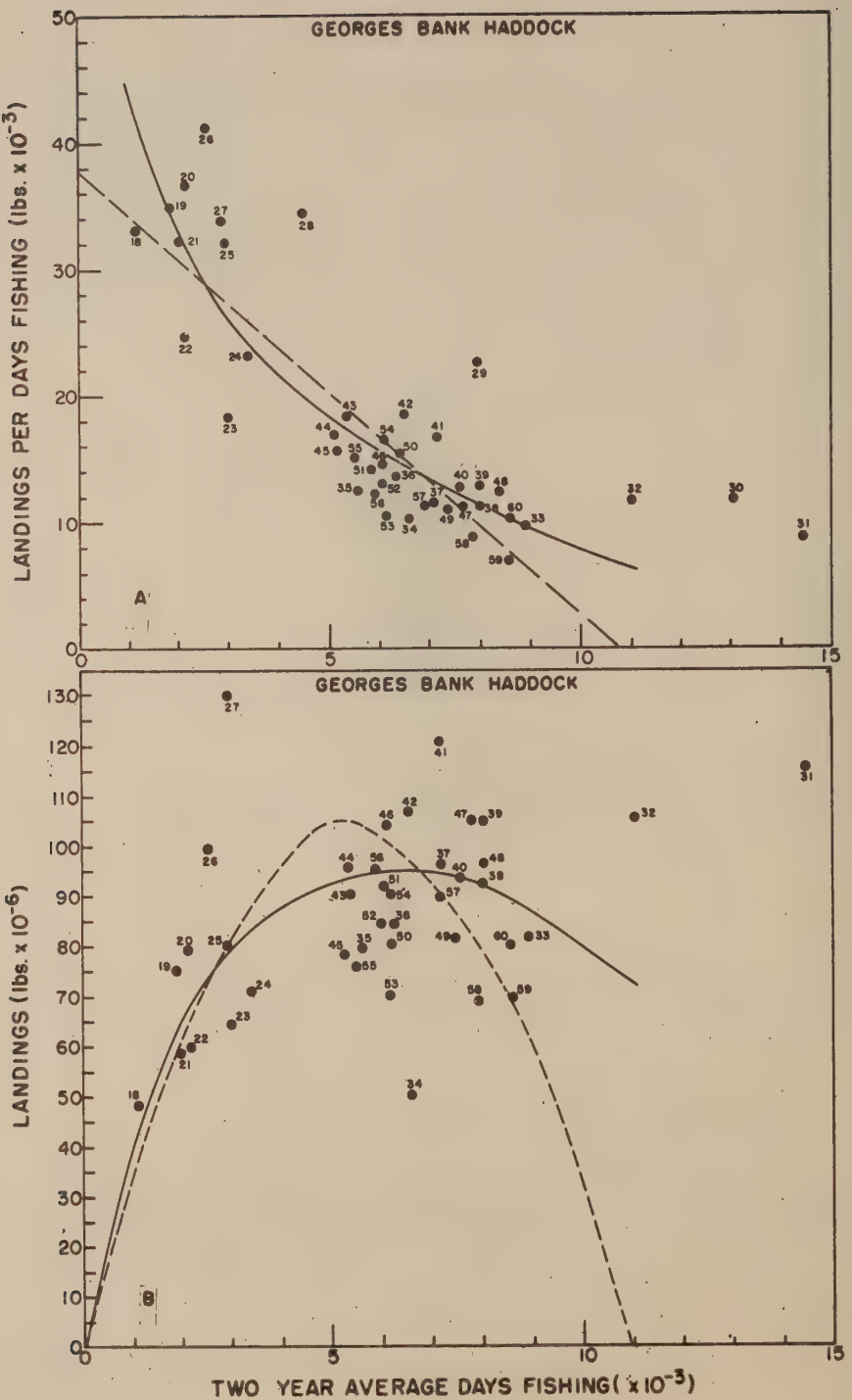


Fig. 11. Haddock yield.

Haddock yield. Data on the landings of haddock caught on Georges Bank have been collected since 1931. These data have enabled us to calculate an index of apparent abundance, in terms of landings-per-standard days fished, and estimate the total effort experienced in each year since 1919. A standard day is that fished by a selected group of large otter trawlers fishing in depths of 30 to 60 fathoms.

Landings-per-days-fished in a given year has been plotted against the two year average of days fished culminating in the given year (Fig. 11a). The observed relationship between these two variables indicates a definite drop in apparent abundance with increasing fishing intensity. A straight line was fitted to these data to approximate the equilibrium, or long-term average relationship. The landings are also plotted against effort, and fitted with a curve derived from the linear relationship above (Fig. 11b).

The analysis indicates that the maximum equilibrium yield is in the neighbourhood of 100 million pounds annually, and at the level of 5 to 6 thousand standard days fishing. A curved line was also drawn in by size, because the landings-per-day and effort variables may be more closely related by a slightly curvilinear relationship, although the variability of the data precludes a more refined estimation at the present time. The curvilinear fit would have the effect of lowering somewhat the maximum yield and increasing the effort level at which it would be obtained to between 6 and 7 thousand standard days.

In either case, recent levels of effort of over 8 thousand standard days exceed that corresponding to the maximum yield, and further increases in fishing intensity would not, in the long run, increase landings: rather: it seems more likely the landings would decrease.

It is of interest to note the rapid increase in landings and effort from 1926 to 1932, apparently stimulated, at least in part, by an increase in abundance in 1926 and 1927. The high effort levels quickly produced a drop in landings-per-day and landings in the years 1930-34, so that by 1935 all three variables had returned to a point close to the estimated equilibrium condition. Because of the non-equilibrium state, the data points for the years 1926-33 were not used in fitting the curves.

HERRING

United States research on herring in the past has been concentrated on the younger stages which support the sardine industry, but recently attention has been directed toward the larger problems of the populations throughout the Gulf of Maine and on Georges Bank.

A statistical system set up in 1947 is providing detailed information on the US landings, some of which is imported from Canada.

Abundance of the sardines is difficult to estimate since there is evidence that

availability to the traps or inshore seines is extremely variable. Success has been achieved in age reading of otoliths so that age determinations can now be made of fish three years old and younger. The US catch is being sampled for age composition of the sardine sizes.

Subpopulations of herring are studied through serological techniques and some meristic work. A new blood group has been found which is a valuable addition to the many factors which must be used to differentiate the subpopulations in the Gulf of Maine. So far nothing has been found to associate the Maine sardine definitely with Georges Bank herring.

Offshore populations are studied for age structure and other population characteristics of all known spawning groups, and sampling of the Georges Bank area for adult and larval herring is under way.

Behaviour and migration studies concentrate on understanding the nature of and reasons for the inshore movements of immature herring. The final experimental phases in development of a suitable long-term herring tag should be completed this winter, and a major tagging effort is planned.

Studies designed to shed light on the environmental factors that control or affect the abundance and availability of herring are divided into two parts: (1) surveys in the Sheepscot-Boothbay-Damarascotta area of Maine where 18 stations are established in three somewhat different environments: Lower estuary, Bay area, and combined weak lower estuarine and Bay, and (2) surveys inshore along the Maine coast. Measurements are made of temperature, salinity, density, currents, transparency, and plankton collections are made monthly. There appears to be a peak in abundance of larvae during the period September-November and sometimes a secondary peak. The collected data are being analyzed to determine the critical period in the life history as related to environmental conditions.

SEROLOGY

In the summer of 1961 attention was directed toward developing a technique for distinguishing haddock blood groups. Blood samples have been processed from about 700 haddock and although problems still remain with storage and processing techniques, some encouraging results have been obtained in finding blood groups.

Tests for isoagglutinations, haddock blood cells vs. haddock blood serum, were run using more than 3600 individual cross-matches with practically no differential results. It was concluded that naturally occurring isoagglutinins in haddock have a low frequency of positive tests and are low in strength of reaction or titre. Consequently isoagglutination tests are not a useful tool in haddock serology.

Heteroagglutinations, haddock blood vs. blood of other species have been made

between haddock blood cells and/or sera and a variety of potential agglutinins such as seed extracts and blood serum from other marine organisms, including four arthropods and 21 fish species. Among these, the best differential agglutinations were obtained in several experiments with inshore blackback flounder serum, and at least three distinct antigen types were distinguished by the absorption technique in one sample of 20 haddock. Problems in obtaining samples and storage of blood made it desirable to seek other reagents, and further tests have not been made with blackback serum.

Tests were conducted with anti-haddock serum from rabbits and chickens, but so far no differential results have been obtained. Still another test matched blood sera from 90 haddock against Hemantigen (a commercially available product containing human type-O cells with many known secondary groupings) with only one questionable agglutination.

Best results have been obtained between haddock cells and rabbit anti-scup serum; every sample tested so far has yielded highly differential agglutinations. Recent tests on 204 haddock from several locations in the Gulf of Maine suggest that there might be gene-frequency differences between areas. Attempts will be made to test anti-scup serum with haddock blood samples from major haddock spawning grounds in March 1963, and also from the waters of eastern Nova Scotia and Newfoundland.

A final technique has been the electrophoretic separation of hemoglobin proteins. With this technique evidence has been reported for a simple two-allele system of hemoglobin types in whiting and cod in the Northeast Atlantic. Hemoglobin patterns have been obtained on 77 Gulf of Maine haddock and in virtually every case an identical 2-band pattern was observed.

SEA SCALLOPS (Placopecten magellanicus)

The Fishery. Pertinent statistics regarding the Georges Bank sea scallop fishery are presented in Table V. It will be noted that the total landings (United States and Canadian combined) increased markedly in 1959, and continued to increase through 1962; the 1962 figure being more than double that of 1959. This phenomenal and unprecedented increase was due to an increased abundance of the shellfish and an increased effort on the part of the Canadians. The days fished by US vessels actually dropped in 1959 and 1960, although US landings increased somewhat due to the high abundance of the scallops.

Abundance. The rather sudden increase in abundance that occurred in 1959 was due to an unusually large year-class of scallops that arrived at commercial size that year. This year-class supported the fishery for four years. It is now declining and we see no similar year-classes coming along.

We have three methods for estimating relative abundance; comparison of quantitative research vessel samples, landings per day on the grounds for the fleet, and

Canadian records of catch per minute towed on commercial vessels carrying sea samplers. For various reasons none of these gives a very precise estimate, but all of them show a decline for the marketable sizes (greater than 95 mm) of about 30 percent in 1962, as compared with 1961.

Table V. Statistics of the Georges Bank Sea Scallop Fishery.

	United States		Canada		Total	Average US Fleet	
Year	Landings lbs x 10^6	Effort Days	Landings lbs x 10^6	Effort Days	Landings lbs x 10^6	Landings per day	Gross Stock ($) per day
1953	16.3	10031	0.3	180*	16.6	1627	717
1954	15.5	9343	0.2	120*	15.7	1671	748
1955	18.3	11619	0.3	190*	18.6	1570	821
1956	17.5	12246	0.7	490*	18.2	1442	778
1957	17.3	10500	1.8	1197	19.1	1650	800
1958	14.4	8775	2.6	1598	17.0	1637	793
1959	18.7	8556	4.4	2098	23.1	2187	1057
1960	21.9	8039	7.5	2601	29.4	2722	949
1961	23.6	8671	10.0	3147	33.6	2719	1030
1962	21.9	9070	13.0*	5400*	34.9	2410	980

* Estimated

None of these methods gives even an approximate measure of the strength of the pre-recruit year-classes. We can say, however, that nowhere on the grounds sampled with the research vessel in 1962, was the year-class to be recruited during 1963 present in large numbers. It is possible, but we believe unlikely, that there are any large concentrations of this year-class in areas that we did not investigate.

BENTHIC STUDIES

Principal work performed by the Benthos Program during the past year was the quantitative benthic fauna study of: (1) the northern Gulf of Maine, and (2) the continental shelf south of Martha's Vineyard and Nantucket Island. Based on the analysis of 100 samples from the northern Gulf of Maine, the macroscopic benthic fauna was found to average 80 grams per square meter of bottom. The fauna was particularly dense (300-1000 g/m^2) off Penobscot Bay, Maine. Moderately dense concentrations occurred on Cashes Ledge and adjacent areas north and east of Cashes. In general, the benthic biomass in the western section of the Gulf of Maine was considerably lower than that occurring in the central and eastern parts of the Gulf. General comparisons indicate that the Gulf of Maine benthos is only about half as dense as that occurring on Georges Bank. Analyses of the samples from south of Martha's Vineyard and Nantucket have not yet been completed. However, preliminary results

indicate the presence of 5 macro-benthic faunal communities. Biomass at the shallow, inshore stations was moderately low (20-40 g/m^2), whereas over most of the shelf the biomass was moderate to very rich (50-300 g/m^2). Exceedingly high faunal density (over 1000 g/m^2) occurred at a few localities, usually associated with aggregations of mollusks. From the analyses made so far, the biomass and faunal composition in this area appears to be generally comparable to that occurring on Georges Bank.

The benthic studies program is providing a rich body of information on the distribution and abundance of bottom fauna which will be used in preparing charts of faunal types, and in providing very useful knowledge for an understanding of the nutritional support of our commercial bottom fish as well as an understanding of the ecosystem dynamics of the area.

HYDROGRAPHY - by Dean F. Bumpus, Woods Hole Oceanographic Institution

WHOI under contract with the USBCF has continued the Oceanographic Observation Post program throughout 1962 from Maine to Georgia at 15 offshore locations (lightships and towers) and at several shore stations. The drift bottle and sea bed drifter program has also been continued.

According to the data so far received from the oceanographic observation posts at Mt. Desert Light, Portland, Boston and Nantucket Lightships, Texas Towers Nos. 2 and 3 (Georges Bank and Nantucket Shoals), and Woods Hole, the temperatures of eastern New England waters were near normal during most of the year 1962. At Woods Hole the water was colder than normal in both November and December and this may prove to be the case also at the other stations when the data for those months are received.

In comparison with 1961 the temperatures of 1962 tended to be somewhat higher during the first half of the year and slightly lower in the latter half.

That the water temperatures remained near normal is perhaps surprising in view of the cold air temperatures which prevailed in New England. Boston, for example, had its coldest year since 1940, the average air temperature being only 49.8°F as compared with a normal of 51.4°F. Nine months, including the last six were colder than normal.

Salinity followed its usual course at most stations; higher in the cold months and lower in the summer and early fall.

At Portland lightship, where the minimum salinities normally occur in the spring following the maximum river runoff, the minimum average salinity was 30.68 ‰ for the month of May following the maximum of river runoff in April at the representative station on the Pemigewasset River. An unusual second peak in the runoff curve in October was followed by a freshening of the water at Portland lightship from 31.67 ‰ in

September to 31.24 ‰ in November. No salinity data are available as yet for October or December so that it is not possible to ascertain the minimum month.

The increase in runoff is attributable to high rainfall in October and November (as much as 300 % of normal in some areas in October) and in particular to a storm on October 5-7 which broke all existing records in eastern sections of New England.

One end product of the drift bottle program will be a series of charts depicting the non-tidal drift along the east coast of North America from Cabot Strait to the Straits of Florida. The reduction of the data for the years 1959, 1960 and 1961 to chart form is now completed. These charts will show on a monthly basis the direction and speed of the drift and also per cent recovery from 30 minute rectangles. The data for 1962 must be added to make the charts reasonably complete. It is apparent that departures from the normal condition of drift are quite frequent. For example, off the coasts of the Mid-Atlantic states the percent recovery of drift bottles released by lightships was higher this year, 1962, and also a large percentage of the bottles released during June and July at the lightships off that coast was recovered to the north, suggesting that the normal non-tidal drift to the south was interrupted and reversed from time to time, Figures 12 and 13. These data require further analysis as to the causes.

Sea bed drifters have become a really useful tool during the past year. Results suggest that the non-tidal drift along the bottom in the Gulf of Maine area is in the same direction, in general, as the surface drift, but about one tenth as fast.

In all this work we have received excellent co-operation from Biological Station, St. Andrews; USFWS Biological Laboratory, Boothbay Harbor; USFWS Biological Laboratory, Woods Hole; USWB, Atlantic Weather Project, Boston; USFWS Biological Laboratory, Sandy Hook, N.J.; Virginia Institute of Marine Science; USFWS Biological Laboratory, Beaufort, N.C.; USC&GS, USCG Lightships and Towers; USAF Weather Observers on Texas Towers.

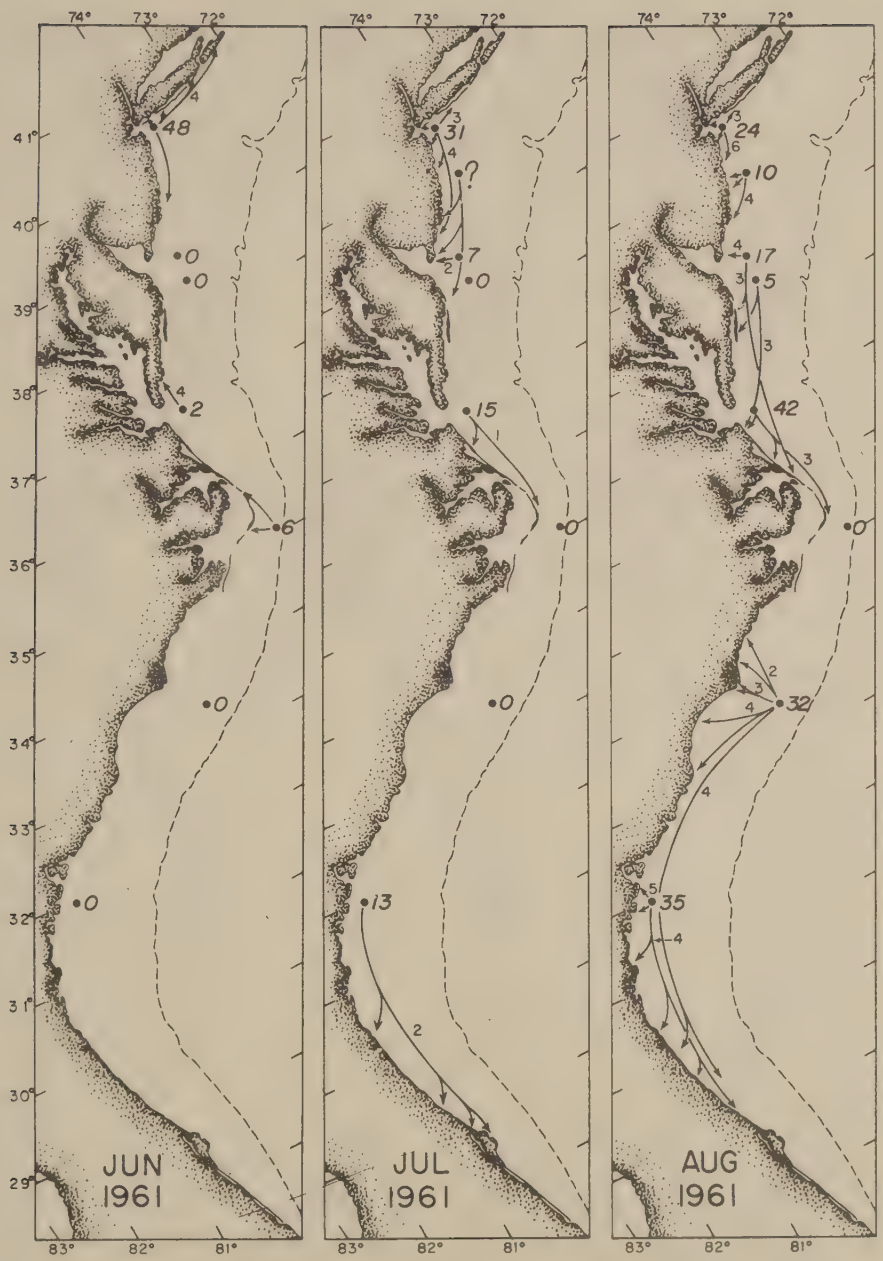


Fig. 12. Recovery of drift bottles released by lightships off the coast of the Mid-Atlantic states, 1961.

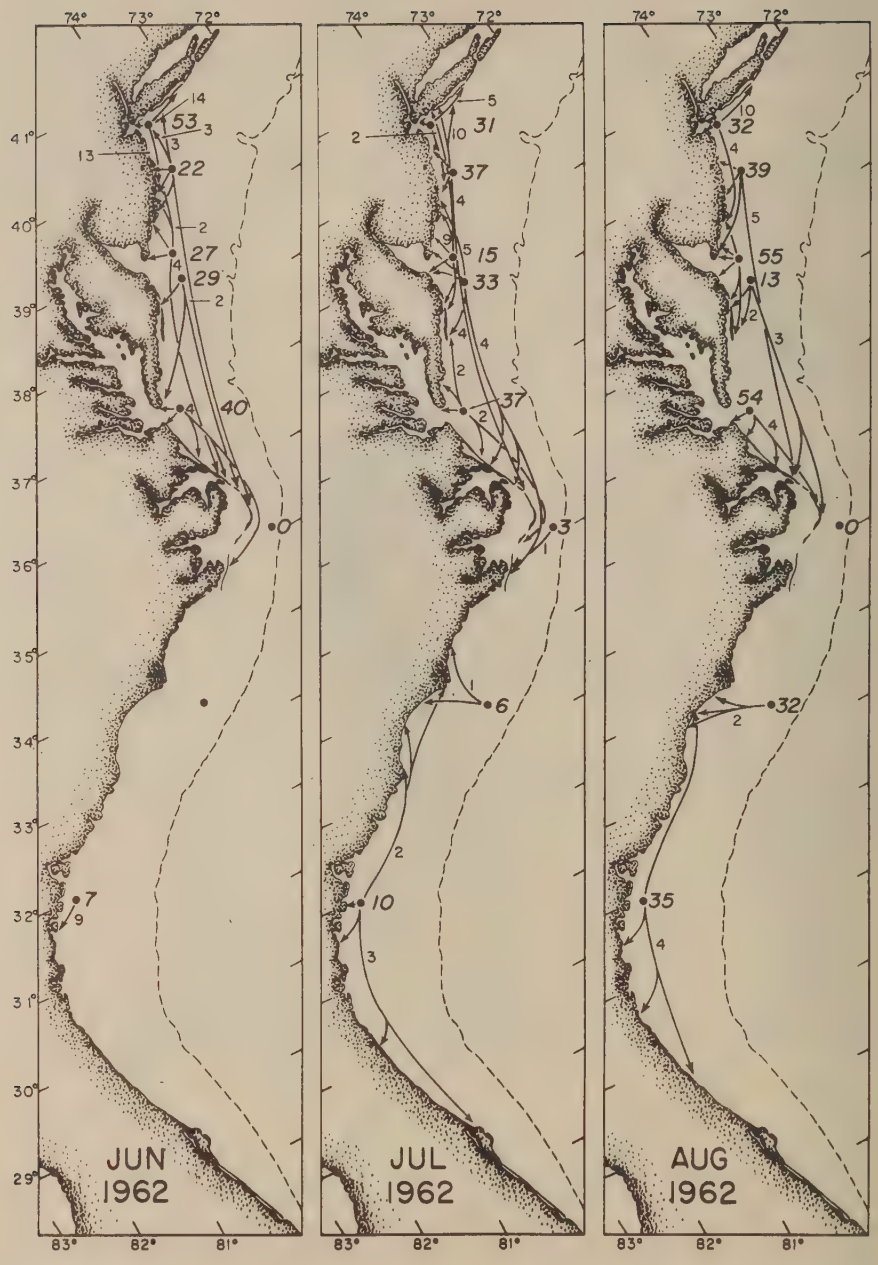


Fig. 13. Recovery of drift bottles released by lightships off the coast of the Mid-Atlantic states, 1962.

REPRODUCTION AND LARVAL DEVELOPMENT OF THE NEW ENGLAND CLAM DRILL, POLINICES DUPLICATUS (SAY) (NATICIDAE: GASTROPODA). Dr. James E. Hanks, Director, Bureau of Commercial Fisheries Biological Laboratory, Milford, Connecticut.

Field observations and laboratory experiments indicate that while the breeding season of P. duplicatus in the vicinity of Woods Hole, Massachusetts is from June to September, when the temperature of the sea water is above 17°C., the gonads of this species contain ova and spermatozoa throughout the year. Drills moved gradually from water at temperatures as low as 2°C. to 20°C. mate after 1 to 2 days and females produce a nidus (egg collar) within 10 to 12 days. The average number of fertilized eggs within a nidus is 5600, each enclosed by a gelatinous capsule.

At a water temperature between 18°C. and 20°C. cleavage of the egg to the 16-cell stage is completed at 12 to 13 hours and development to a ciliated trochophore stage is reached by 26 hours. Within 2 to 3 days an early veliger stage is attained and larvae are released from the nidus at 10 to 12 days. After about 25 days at pelagic existence, during which the larvae feed on phytoplankton algae, a well-developed foot is present (the pedoveliger stage) and the larvae metamorphose at about 30 days. Recently metamorphosed drills measure 0.5 to 0.7 mm. (shell height) and are carnivorous, feeding mainly on tiny gastropod and pelecypod mollusks.

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CHEMICAL CONTROL OF THE GREEN CRAB, CARCINUS MAENAS (L.)

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Boothbay Harbor, Maine

ABSTRACT

Development of a method to protect soft-shell clam (Mya arenaria L.) stocks from green crab predation is considered necessary for efficient management of the New England clam fishery. The development of new organic pesticides has suggested practical and economical methods of controlling this predator. Bait fish soaked in lindane and attached to long trawl lines proved to be an effective barrier to green crabs. The barrier not only prevented crab movement into the protected area, but reduced resident crab populations. Experiments at Kittery, Maine, resulted in a 76 per cent decrease in crab catch nine weeks after the barrier was established. Catches of all traps declined during the experimental period with the greatest decrease in those traps closest to the barrier. Significant differences between trap catches inside the barrier and those outside the barrier were evident after four weekly baitings. The barrier restricts toxic bait to a predetermined area, is lethal to arthropods that feed on the bait, and is relatively inexpensive to maintain.

INTRODUCTION

The green crab, Carcinus maenas (L.), is the most important predator of the soft-shell clam, Mya arenaria L., north of Cape Cod. Low wire fences, developed to curtail crab predation (Smith, 1954, Glude, 1955), have not been entirely satisfactory and alternative methods of crab control are needed. Research at the Bureau of Commercial Fisheries Biological Laboratory, Milford, Conn., on chemicals as predator control agents has been most promising (Loosanoff, Hanks and Ganaros, 1956; Loosanoff, 1959, 1960; Shearer and MacKenzie, 1959; Loosanoff, MacKenzie and Shearer, 1960). When specific pesticides are found, there remains the problem of using these materials in the marine environment without undesirable side effects. Although many apparently excellent methods of predator control with chemicals are available (Loosanoff, 1960), further studies will be made in the hope of expanding the application of this potentially valuable management tool. This paper describes one method, developed at the Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine, to control green crabs with a commonly used pesticide.

EXPERIMENTS IN CRAB CONTROL

Lindane is the gamma isomer of benzene hexachloride (BHC). It is by far the most toxic of the several isomers of BHC and has been widely used as an agricultural pesticide (Metcalf, 1955). Crude BHC has been used in aquatic predator control by Jordan (1955) who found that spray applications at dilutions of 6.5 ppm protected young rice seedlings from destruction by the crab Sesarma africanum. In 1953, John Hurst, Jr. (personal communication), of the Maine Department of Sea and Shore Fisheries, found that lindane was extremely toxic to marine crustacea and that concentrations as low as 1.0 ppm were lethal to green crabs within 48 hours. Bait fish, soaked in lindane, attracted crabs to the toxic substance, and appeared to offer a convenient method of handling and restricting the action of organic pesticides in the marine environment.

In 1958, preliminary experiments were conducted to test whether a band of toxic bait, interposed between a clam-producing area and the source of crab recruitment, would act as a barrier to crab predators. A small creek system (Area 1 in Fig. 1) at Wells, Maine, was chosen as a study area on the basis of its size, accessibility, and existing records of crab and clam populations. Trapping records from the previous year showed that numbers of crabs and their movements in this creek were similar to those in other creek systems at Wells. The barrier was established during the middle of June by spreading, at low tide, a band of toxic bait 30 feet wide across the mouth of the creek. Small pieces of fish (alewives) used as bait had been soaked in lindane [1] for 24 hours at the proportion of one pint pesticide to one bushel of fish, a concentration found lethal to green crabs in previous experiments. The barrier was renewed with freshly treated bait every 2 weeks. Results were evaluated from the catch of four crab traps, two inside the barrier and two outside (Area 1, Fig. 1) which were fished every week. Figure 2 shows that with no pesticide barrier the average monthly catch, based on the weekly catch of green crabs in each trap, was similar in all three areas during 1957. The data for 1958 demonstrate a definite reduction in crab abundance in the experimental area, while the two control areas again exhibited similar patterns of population increase. Lindane had a definite impact on the weekly crab catch which was always lower in the week following bait renewal than in the week preceding (Fig. 3). Subsequent sampling of crabs and clams in the creek

[1] Lindane was in the form of Isotox Spray #200 (20% gamma isomer content) obtained from the California Spray Chemical Corp., 622 State St., Springfield, Mass.

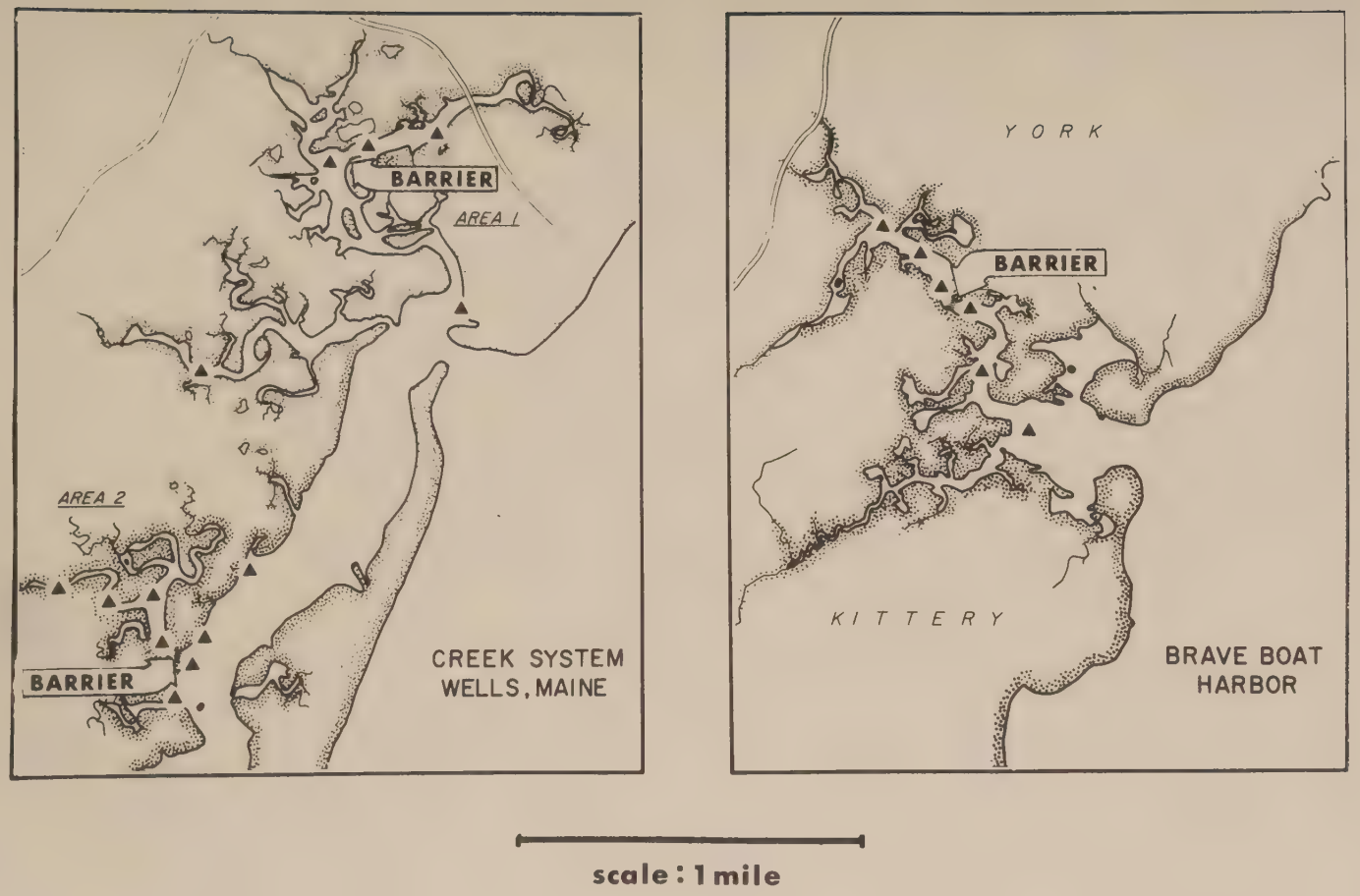

Fig. 1. Experimental areas at Wells and Kittery, Maine, showing location of traps (solid triangles) and barriers (hatched portions).

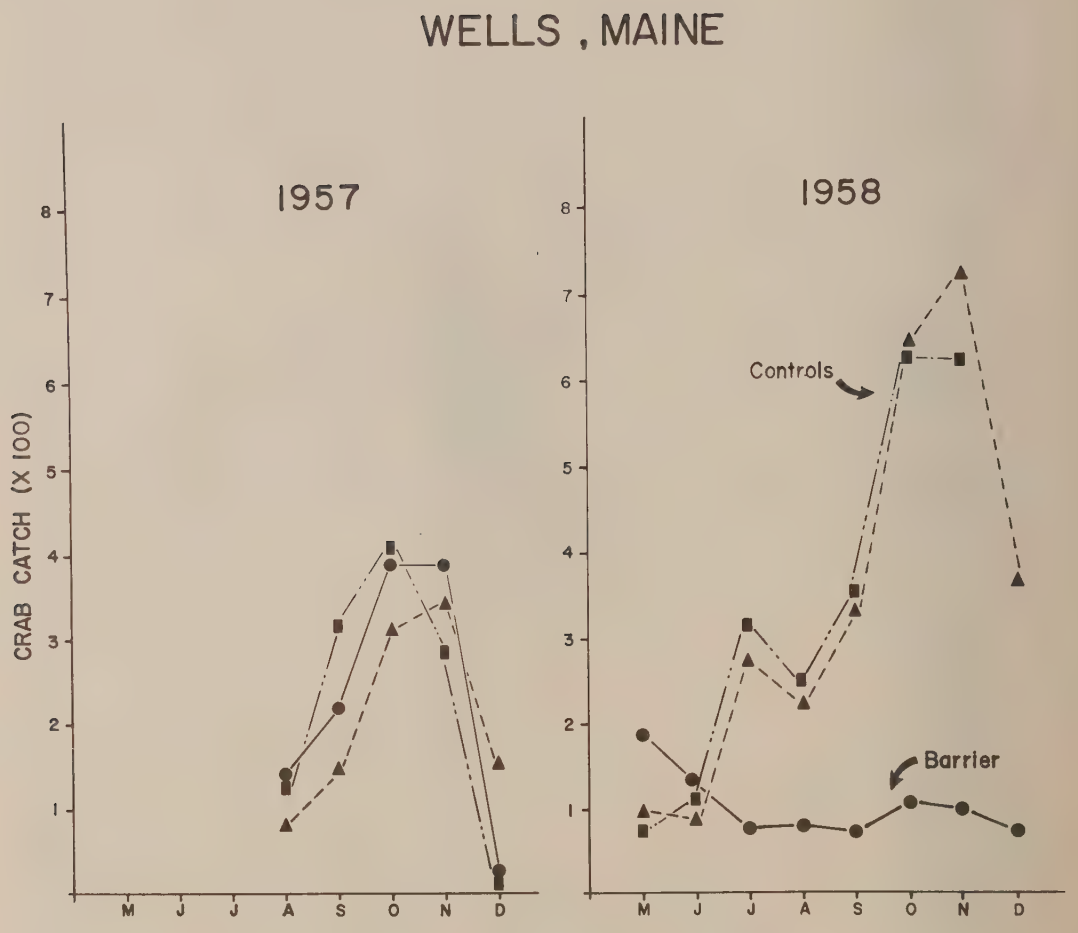

Fig. 2. Average monthly catch (in hundreds) of green crabs at Wells, Maine. Area 1 = ● , Area 2 = ▲ , and Control Area = ■ .

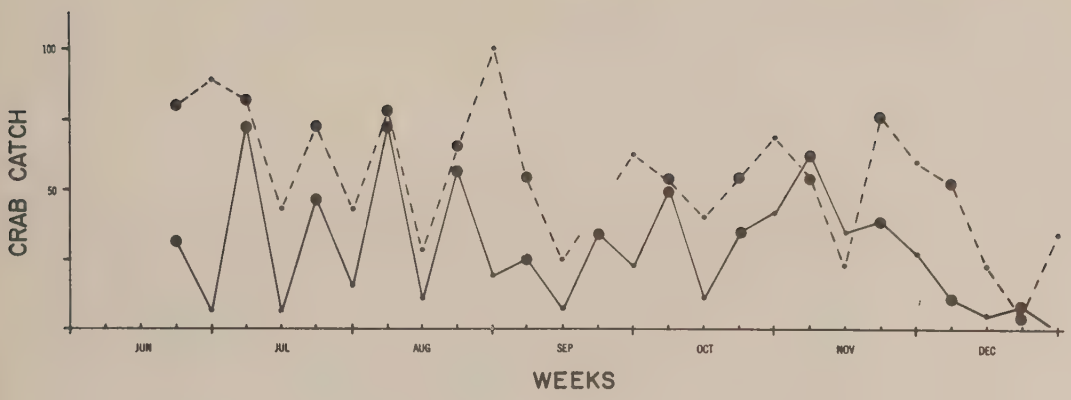

Fig. 3. The effect of lindane on the weekly green crab catch of two traps, one inside (solid line) and one outside (dashed line), near the barrier. Enlarged dots indicate dates of bait renewal.

indicated that the crab populations remained at a very low level throughout the winter. Survival of juvenile clams larger than 3 mm (a minimum size for crab predation) was much greater and in sharp contrast to other nearby sections of flats. Samples of clams in the 4 to 10 mm size range, taken in May 1959, produced means of $16/ft^2$ for the protected area and only $3/ft^2$ for the non-protected areas. Even as late as August 1959, mean numbers of juvenile clams in the same size class were $18/ft^2$ in protected flats and $1.5/ft^2$ in the other areas.

The experiment showed that the broadcast method of bait distribution was not satisfactory as bait was rapidly washed away by the strong currents thereby weakening the barrier and possibly carrying toxic bait into areas inhabited by commercially important crustacea. Bait distribution was also restricted to the period of low tide, often an inconvenience, and some training was required to spread the bait properly. These difficulties were corrected in the following experiments by using specially constructed trawl lines (Fig. 4). During the 1959 season, five trawl lines were stretched across the mouth of Pope's Creek in Wells, Maine (Area 2, Fig. 1). Each line consisted of a length of 5/16 inch diameter manilla rope, commonly referred to as "pot-warp," from which No. 14 cod hooks were suspended at 2-foot intervals. The distance between trawls was about 15 feet, and each line was weighted to hold it on the bottom. Whole fish, soaked overnight in lindane (1 pint of pesticide to 1 bushel of fish), were placed on the trawl hooks and renewed every 2 weeks. Unfortunately, the Wells crab population was

Fig. 4. Photograph of a barrier trawl line. The line has been supported on a wooden stake to provide a clearer view.

reduced in 1959 by a severe winter mortality. Trapping for green crabs was ineffective and evidence for barrier control of crab activity was unobtainable.

A concurrent and similar experiment in Brave Boat Harbor, Kittery, Maine (Fig. 1) provided data for 1959. The winter mortality had lowered the crab population, but sufficient numbers of crabs survived to provide evidence of the barrier effect. Two trawl lines were baited every week. Six traps, three inside and three outside the barrier, were fished daily. The average monthly catch for the inner traps and the outer traps is compared in Fig. 5 for 2 years, 1958 (without a barrier) and 1959 (with a barrier). The 1959 data show that both inner and outer catches declined during the trapping period. In addition, the general trend in catches with the barrier is directly reversed from the trend of catches without the barrier in the previous year. Traps closest to the barrier, both inside and outside, consistently exhibited the lowest catches, while the outermost traps maintained a higher level of catch. Student's "t" test, as applied to these data, showed that there was a significant difference at the 1 per cent level between the average catch per baiting period inside and outside, after the fourth baiting period. Fig. 6 demonstrates the impact of the lindane barrier on the entire creek system. There is a decreasing pesticide effect with increasing distance, and trap catches inside are consistently lower than catches equally distant from the barrier on the outside. This latter factor is ascribed to continuous recruitment from sources outside of the experimental area and indicates control of crab movement into the area protected by the barrier.

The project was terminated in October, prior to the period of most intense crab activity, because bait fish were unobtainable. Previous crab trapping in both Wells and Kittery indicated that the catch in the outermost trap would have shown a marked increase during this period, while those nearer to the barrier, particularly those inside, would have continued to decline. Even during the short experimental period, the average daily catch per trap inside the barrier was reduced from 44 to 14 crabs, or 76 per cent. The greatest decrease (80 per cent) occurred in the inner trap, nearest the barrier, while the least decrease (69 per cent) occurred in the outermost trap.

Clam samples, taken throughout the Brave Boat Harbor area in the winter of 1959, indicated an excellent survival of small Mya inside the barrier.

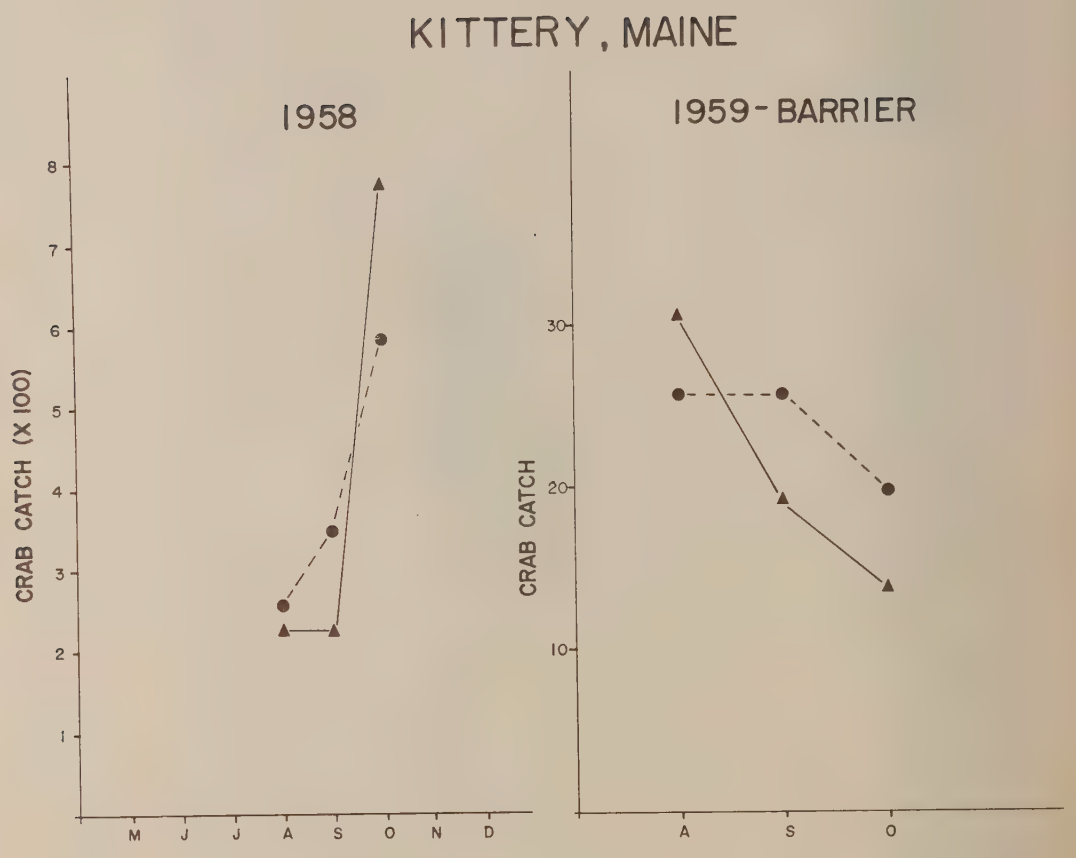

Fig. 5. Average monthly catch (data for 1958 in hundreds of crabs; for 1959 in actual numbers) of green crabs at Kittery, Maine. Inner trap (s) = ▲ ; outer trap (s) = ● . Note: the graphs are <u>not</u> drawn to the same scale.

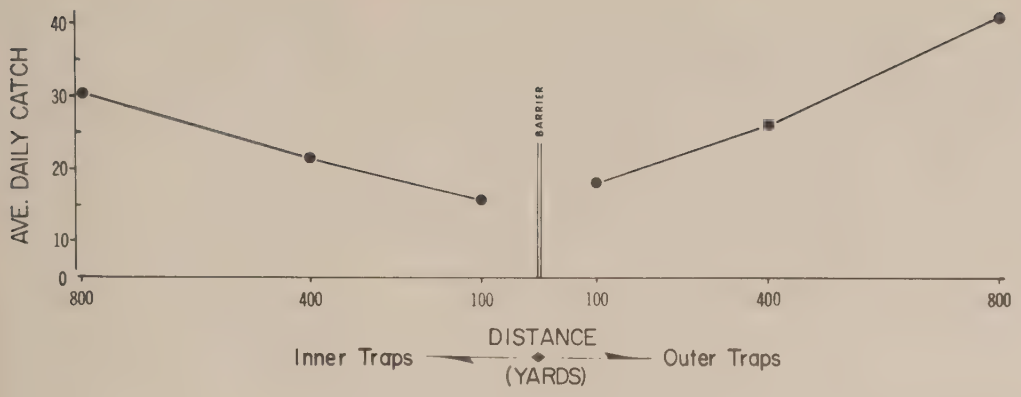

Fig. 6. Average daily catch for 1959 compared with distance from barrier site for six traps at Brave Boat Harbor, Kittery, Maine.

DISCUSSION

A predator control method must meet several requirements if it is to become a practical management tool. The method must be inexpensive, relatively safe to use in the presence of other organisms, and amenable to maintenance by unskilled labor.

Table 1 lists the items and costs of three different barriers and compares the cost per week in each area. The table does not list the cost of trawl line and hooks because these items become negligible when amortized over the entire life of the barrier. The expense of the barrier could be further reduced by use of cheaper bait and pesticide preparations.

Although lindane has been a satisfactory pesticide for research work (inexpensive, easily obtainable, specific in action, low aqueous solubility) considerable modification of the chemical part of the barrier is possible and, perhaps, desirable. Loosanoff, Hanks and Ganaros (1956) listed over 100 compounds that would kill green crabs and many other materials have become available. Lindane, however, can be a very selective toxin if used properly. Fish mortalities have been observed in relatively high dilutions of lindane (P. A. Butler, U. S. Bureau of Commercial Fisheries Biological Laboratory, Gulf Breeze, Florida, personal communication), but no fish deaths have ever been recorded in our laboratory experiments with lindane-soaked fish bait or in field experiments with the barrier. The only observed mortalities

Table 1. Cost of materials and labor for pesticide barriers

1958 Season

Wells, Maine—Upper Landing Creek, June to December.

13 baitings @ 2 bushels of fish:

Labor	13 man hours	@	$1.50/hr.	=	$19.50
Fish	26 bushels	@	1.50/bu.	=	39.00
Lindane	26 pints (3 1/4 gal.)	@	10.39/gal.	=	33.77
					$92.27

Materials only = $72.77

Cost per week: $3.55

1959 Season

Wells, Maine—Pope Creek, June to December.

12 baitings @ 3 bushels of fish:

Labor	18 man hours	@	$1.50/hr.	=	$27.00
Fish	36 bushels	@	1.50/bu.	=	54.00
Lindane	36 pints (4 1/2 gal.)	@	10.39/gal.	=	46.75
					$127.75

Materials only = $100.75

Cost per week: $5.32

Kittery, Maine—Brave Boat Harbor, August to October.

9 baitings @ 1 bushel of fish:

Labor	9 man hours	@	$1.50/hr.	=	$13.50
Fish	9 bushels	@	1.50/bu.	=	13.50
Lindane	9 pints (1 1/8 gal.)	@	10.39/gal.	=	11.69
					$38.69

Materials only = $25.19

Cost per week: $4.30

have been in sand shrimp, Crago septemspinosus, apparently susceptible to trace amounts of lindane. Chin and Allen (1957) found that lindane concentrations of 50 parts to one billion were lethal to two species of penaeid shrimp. Sand shrimp repopulate the treated area within one tidal cycle after application indicating that the observed mortalities were produced by excess lindane preparation washed from the surface of the bait fish and not from material leached out of the flesh. The low solubility of the pesticide when incorporated with the natural fish oil is advantageous because only those arthropods that feed directly on the bait and only those that are susceptible to very small concentrations of ingested lindane are affected.

Though simple to maintain after installation, the barrier must be carefully located on the basis of preliminary area surveys. The barrier method is particularly suited to the behavior of green crabs since their habitat requirements differ from those of most commercially important arthropod species. Lobsters (Homarus americanus), equally susceptible to lindane, are rarely found in the same area and the rock crab (Cancer irroratus) is seldom found in as shallow water as the green crab. Thus, by placing the barrier no deeper than the mean low water line, toxic effects on other species can be effectively eliminated. The examination of predator feeding habits and determination of local hydrographic features should also be employed in locating barrier sites.

The present data support the use of the pesticide-bait fish barrier as a practical means of crab predator control. The barrier method is applicable to many arthropod predators, where habitat requirements do not intergrade with those of commercial species or, alternatively, when species-specific pesticides can be found. With modifications, the method can possibly be utilized to control predators other than arthropods, provided they can be attracted by bait materials.

The barrier is particularly valuable where physical conditions such as tide, soil type and currents are most difficult; but it is restricted to intertidal or shallow water application. The barrier's advantage in restricting organic toxins to predetermined localities is obviously important in preventing pesticide pollution of the coastal waters.

Based on methods suggested by these studies, the pesticide-bait fish barrier is undergoing experimental trials in Maine and Washington to protect commercially important shellfish stocks.

LITERATURE CITED

Chin, E., and D. M. Allen. 1957. Toxicity of an insecticide to two species of shrimp, Penaeus aztecus and P. setiferus. Texas J. Sci. 9:270-278.

Glude, J. B. 1955. New fence design successful in keeping out green crabs. Maine Coast Fisherman 10(4):22.

Jordan, H. D. 1955. Control of crabs with crude BHC. Nature 175: 734-735.

Loosanoff, V. L. 1959. Some effects of pesticides on marine arthropods and mollusks. Trans. 1959 Seminar, U. S. Dept. Health, Education, and Welfare, Publ. Health Serv. Tech. Report W-60-3: 89-93.

Loosanoff, V. L. 1960. Recent advances in the control of shellfish predators and competitors. Proc. Gulf and Caribbean Fisheries Inst., 13th Ann. Session (November 1960): 113-127.

Loosanoff, V. L., J. E. Hanks, and A. E. Ganaros. 1956. Chemical control of shellfish enemies promising. Nat'l Fisherman 37(11): 16, 40.

Loosanoff, V. L., C. L. MacKenzie, Jr., and L. W. Shearer. 1960. Use of chemicals to control shellfish predators. Science 131: 1522-1523.

Metcalf, R. L. 1955. Organic insecticides; their chemistry and mode of action. Interscience Publishers, New York, 393 pp.

Shearer, L. W., and C. L. MacKenzie. 1959. The effects of salt solutions of different strengths on oyster enemies and competitors. Proc. Nat'l Shellfish. Assoc. 50:97-103.

Smith, O. R. 1954. Fencing in flats may save some clams from green crabs. Maine Coast Fisherman 8(8):20.

OCCURRENCE OF AN UNUSUAL MOLLUSK ON THE COAST OF MAINE

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Bureau of Commercial Fisheries Biological Laboratory
Boothbay Harbor, Maine

During the summers of 1955 and 1956, while engaged in studies of the benthic invertebrate fauna of the Sheepscot River estuary and Booth Bay, I obtained six specimens of the small worm-like mollusk *Chaetoderma nitidulum* Loven. The animals were captured with a clam-shell dredge at depths ranging from 26 to 100 feet. Individuals measured ½ to 1 inch in length and about 1/16 inch in diameter. The living animal is quite beautiful, with a shimmering coat of silvery spicules—shell remnants of its molluscan inheritance (Fig. 1). The head is marked by an annular constriction of the tubelike body while the terminal end bears two delicate gill structures protruding from a common respiratory-excretory cloaca. The sexes are separate, with only a single gonad in each individual. *C. nitidulum* lives on or in the marine bottom sediments ingesting soil and digesting the organic material obtained. They were found to inhabit the top 1 to 1½ inches of soft, mud-clay sediments and were associated with a community of small, bottom-dwelling invertebrates dominated by the pelecypod *Yoldia proxima* and the polychaete *Nephtys incisa*.

Figure 1. *Chaetoderma nitidulum*; a small, bottom-living, worm-like mollusk obtained from the soft mud sediments of Ebenecook Harbor in the Sheepscot River estuary. Actual length of this specimen was about 3/4 inch.

Because of archaic molluscan characteristics, *Chaetoderma nitidulum* has been placed in the class Amphineura and the order Aplacophora (Solenogastres). It has been recorded from most coastal environments in the northern hemisphere (Nierstrasz and Stork, 1940; Thorson, 1951) including the Pacific coast of the United States (Hartman, 1955). *C. nitidulum* was reported by Verrill (1874) from Casco Bay, Maine, and by Whiteaves (1901) from Passamaquoddy Bay and the coast of Nova Scotia. Heath (1918) and Johnson (1934) reviewed the distribution on the eastern coast of North America referring to Verrill's collections in Casco Bay. Prior to the present specimens, the mollusk collection of the Museum of Comparative Zoology at Harvard University contained no examples of the Aplacophora (Dr. Ruth Turner, MCZ, personal communication).

Thus, *C. nitidulum* may occur commonly in the Gulf of Maine, but has been rarely observed and probably not collected for almost half a century.

Literature Cited

Hartman, O. 1955. Quantitative survey of the benthos of San Pedro Basin, Southern California. Part 1, Preliminary results. Allan Hancock Pacific Expeditions 19(1): 1-185.

Heath, H. 1918. Solenogastres from the eastern coast of North America. Memoirs Museum Comparative Zoology, Harvard College, 45(2).

Johnson, C. W. 1934. List of the marine mollusca of the Atlantic coast from Labrador to Texas. Proceedings Boston Society Natural History 40(1): 1-204.

Nierstrasz, H. F., and H. A. Stork. 1940. Monographie der Solenogastres des Golfes von Neapel. Zoologica 99: 1-92.

Thorson, G. 1951. Scaphopoda, Placophora, Solenogastres, Gastropoda, Prosobranchiata, Lamellibranchiata. Medd. Groland 81(2): 3-117.

Verrill, A. E. 1874. Exploration of Casco Bay by the U. S. Fish Commission, in 1873. Proceedings American Association Advancement Science 1873, pp. 340-395.

Whiteaves, J. F. 1901. Catalogue of the marine invertebrata of Eastern Canada. Geological Survey Canada, Publication No. 772, p. 271.

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King Crab Tagging Methods in Alaska
In North Atlantic Fish Marking Symposium
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International Commission for Northwest Atlantic Fisheries

42.
King Crab Tagging Methods in Alaska

By
MURRAY L. HAYES*

King crabs, *Paralithodes camtschatica* (Tilesius), have been harvested commercially by Alaska fishermen since at least 1909, but the catch remained small until after World War II when processing and marketing problems were solved. From 1945 to 1950 the annual catch in Alaska increased from 0.2 million to 1.5 million pounds. Since 1950 the rate of annual increase has been rapid, and 27 million pounds were taken in 1960. This growth continues, with catches in 1961 running ahead of those in 1960.

King crabs are known to occur in the coastal waters of Alaska from St. Lawrence Island in the Bering Sea to the southern part of the Alexander Archipelago. The Alaska fishery has developed in four local areas however: the southeastern Bering Sea the waters south of the Alaska Peninsula from Shumagin Islands to False Pass, the waters surrounding Kodiak Island, and Kachemak Bay in Cook Inlet (Fig. 1). Japanese and Russian fishermen take large numbers of king crabs in the Bering Sea. In Alaska, crabs are taken with pots (traps), otter trawls, and ring nets, pots taking the majority of the catch. Tangle net gear is illegal. Females are protected, and the minimum size for males is $6^1/_2$ inches, or 165 mm in carapace width.

Biology of the king crab is fairly well known (Marukawa, 1933: Weber and Miyahara, in press; Bright et al., 1960; and Powell, 1960). Crabs mate in relatively shallow water in early spring. Eggs are spawned and attached to the swimmerets beneath the

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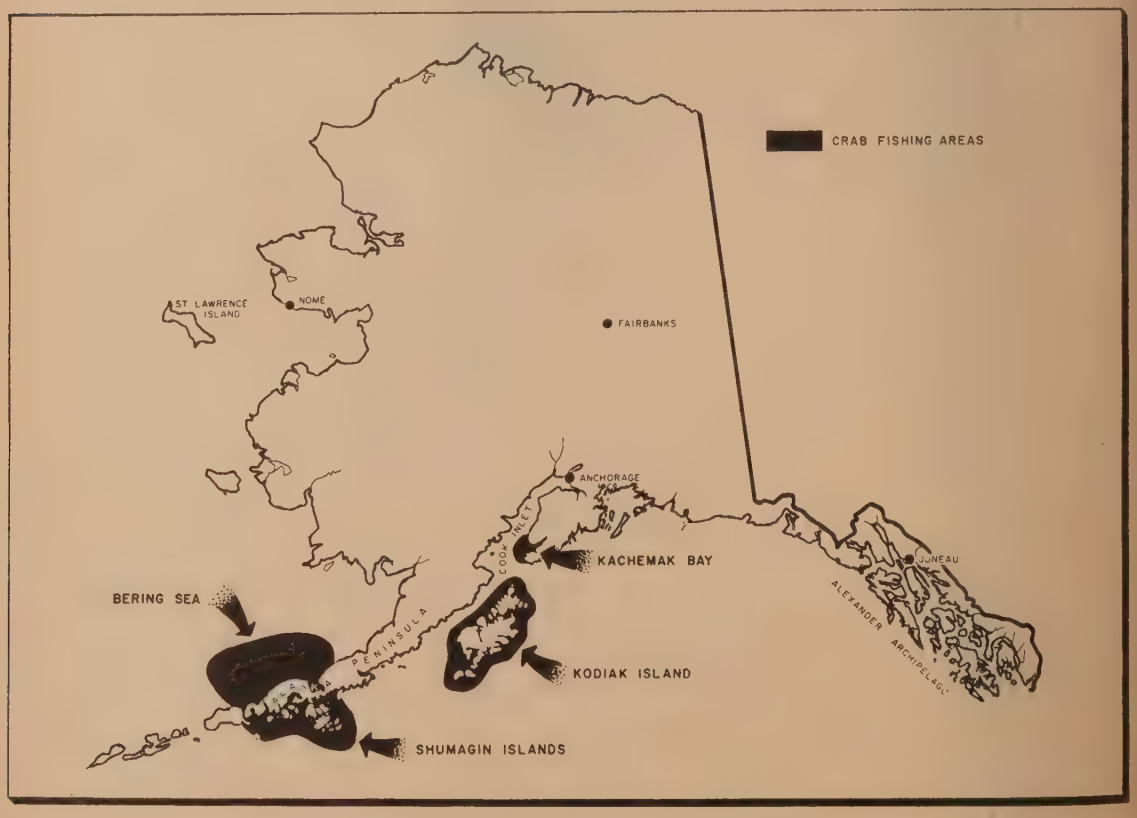

Figure 1. Alaska, showing the four principal king crab fishing areas.

domen of the newly molted female, where they
elop for about 11 months before hatching into
-swimming larvae. There are five planktonic
al stages which take about 6 weeks to complete.
small crabs then settle to the bottom and begin the
thic phase of their life history. Growth depends on
t frequency and size increase per molt. In both
s molting occurs several times per year in the
enile stages, becoming less frequent as size in-
ases. After sexual maturity molting is annual in
ales. In males it is progressively annual, biennial,
even triennial as age increases. Growth studies
icate that king crabs reach sexual maturity in
ut 4 to 5 years. Males reach the legal minimum
in 6 or 7 years, at which time they weigh about
kg. The largest male measured in recent years
caught in Kodiak and weighed 10.1 kg, was
mm in carapace length and 272 mm in carapace
th.

In Alaska, research on king crabs has developed in
allel with the growth of the fishery. The U.S. Fish
l Wildlife Service started exploratory fishing,
nological studies, and biological investigations in
0. This work was interrupted by the war. It was
until 1953 that the Alaska Department of Fish
l Game started a modest research program on king
bs at Kodiak. In 1954 the research program of the
ternational North Pacific Fisheries Commission
an in the Bering Sea. In 1957 the Bureau of
mmercial Fisheries initiated studies on the south
e of the Alaska Peninsula and in Cook Inlet at
Kachemak Bay. All of these programs relied on
ging studies for information on movements and
grations, growth, and mortality.

King crabs share with other crustaceans the
aracteristic that growth in size can occur only
mediately after molting and before hardening of the
v exoskeleton. All hard parts are lost during
lysis and therefore cannot be used for age de-
mination. Also, since tags placed through any of
l hard parts would be lost in molting, some other
thod of attachment is required for long-term tag
ention. For these reasons a tagging method that
mits tag retention through successive molts is
ential to a study of growth or long-term move-
nts.

After reviewing early tagging methods and carefully
serving the molting process, Ed J. Huizer (*In*
aska Department of Fisheries, 1954) perfected the
thod of tagging that has proved successful to date.
e tag is inserted through the muscular isthmus
ween the posteriodorsal portion of the cephalotho-
and the abdomen. Here the isthmus is covered
h a parchmentlike chitinous membrane that is
e of the first parts of the exoskeleton to slough
ay during ecdysis. The molting crab exsheaths

Figure 2. "Spaghetti" type loop tag being inserted through the isthmus of large female king crab. (Photo by courtesy of Alaska Department of Fish and Game).

through a posterior split between the abdomen and the carapace by means of a series of alternate body shifts. Since the tag is attached to the arthral muscle in the isthmus, it is freed at the time of this split and does not appear to hinder molting.

A "spaghetti" type loop tag is used on adult crabs (Fig. 2). It is made from a 12-inch length of polyvinylchloride plastic tubing, with an oval plastic button bearing identification and a serial number. In placing the tag, the carapace and abdomen are spread to expose the isthmus. The tag is then threaded through the muscular part of the isthmus with a curved stainless steel needle. Care must be taken to avoid the large blood sinuses anterior to the muscular part. The two ends of the tubing are brought together and tied in an overhand knot. The trailing ends of the "spaghetti" provide conspicuous identification of tagged crabs even at some distance. After tagging measurements are taken and data recorded. The crab is immediately returned to salt water where recovery from tagging shock appears to be rapid. Salt water seems to promote blood clotting and consequently to prevent excessive bleeding. Similar tagging techniques with smaller materials have been successful with crabs as small as 25 mm in carapace length.

Immediate tagging mortality is small. In several tagging experiments crabs were kept in holding boxes from 1 to 3 days after tagging. Mortality in these periods was less than 1 percent. Of 2886 crabs tagged in Kachemak Bay in June 1960, 15 appeared weak or were dead after the post-tagging holding period. Although some of the weak crabs might have survived, all were discarded. After this same period careful inspection of the tagged crabs showed no initial tag loss.

Tag loss over longer periods of time has been studied by use of floating and submerged holding boxes and cages. Powell (personal communication) of the Alaska Department of Fish and Game placed several large underwater pens on the bottom of Kodiak harbor, which he tended periodically by means of free-diving equipment. Tag retention over a period of nearly 10 months was studied. Although some crabs escaped from the confines of the cages, those remaining showed tag losses of 38 percent (19 of 50) after 170 days and 68 percent (34 of 50) after 291 days. Tag losses were of two kinds. Sometimes the plastic tubing was severed, leaving a hole scar in the isthmus. Other times the entire loop was ripped out of the isthmus, leaving a cut scar. Tag loss from these experiments was very high, but the results are not considered conclusive. The artificial conditions under which the crabs were held may have caused excessive tag loss.

In another experiment, conducted at Kachemak Bay, 86 king crabs were tagged and kept in surface holding pens. On 51 of these crabs tags were tied with overhand knots and on the remaining 35 crabs with square knots. After 22 weeks no tags were lost among the overhand-knot group, but five tags, 14 percent, were lost among the square-knot group. Tag loss is being further studied by additional holding and double-marking experiments.

Tag return is the most important aspect of any marking program. Perfect tagging methods are to no avail unless observations or returns are made. In Alaska, tagging programs for salmon and halibut have been used for more than 30 years, and more or less standard procedures have been adopted. Fishermen are well acquainted with such programs. In Kachemak Bay a reward of one dollar has been paid for each tagged crab reported. Recently, the reward was increased to two dollars. The additional dollar is the approximate market value of a legal sized crab.

Fishermen are paid for tagged crabs when they make deliveries to the processing plant. At these plants the tagged crabs are placed in holding tanks, held for examination by biologists, and then released.

Each fisherman and processor is supplied with tag return forms. On one side of this form is a map on which the fisherman records the location of capture of each tagged crab caught. On the other side are instructions and blanks for the fisherman's name, the tag number, and the date. When these forms are returned to the biologist, he adds location of tag release, original and recovery measurements, growth data, previous returns, and any other pertinent notes on the returned crab. A copy is made and the original tag return form is sent back to the fisherman for his information and as his record for the specific tagged crab caught. Tag returns are summarized at intervals and the results posted on bulletin boards in each processing plant and the field laboratory. In this way fishermen are informed of the progress of the tagging program as a whole. Other information is supplied to the fishermen by means of brief non-technical information bulletins posted along with tag summary charts at processing plants, and by publicity in the local newspapers. Frequent personal contacts and prompt return of information allow the fishermen a measure of personal participation in the program and have greatly improved tag returns.

Failure to detect recaptured tagged king crabs is believed low because of the conspicuous nature of the tag used and the fact that crabs are handled individually at least three times before processing: (1) when removed from the crab pot; (2) when unloaded from the boat hold, and (3) when butchered at the processing plant. Of more than 2400 tags returned from Kachemak Bay experiments, fewer than 10 were from the butchering stage, the final examination where tags might be detected.

Analysis of data is simplified by use of punch card methods. Original tagging data punched into IBM cards include: tag number, carapace length and width, weight, release location, release depth, and remarks. These cards have fields reserved for recovery information. When recoveries are made, the data are punched into separate cards of the same format as the original tagging card. These are sorted into the original tag decks and the data transferred to the master card. Second and third returns are placed on separate cards and marked by means of a special code.

Locations are recorded by a grid system that measures distance north and east from a reference location. Straight-line movements are easily calculated from the co-ordinates of release and return, by use of the elementary distance and direction formulas of analytical geometry.

Machine tabulations of these cards are made periodically and are sent to field personnel. Together with the original tagging plan these supply a complete history of the tagging program up till the date of the last return cards. In this way information and preliminary analyses are available to field biologists with very little delay.

Summary

The commercial fishery for king crabs, *Paralithodes camtschatica*, has developed since World War II. Research on the species includes tagging to study movements, migration and mixing, growth, and mortality. In tagging, a spaghetti-type loop tag is threaded through the muscular isthmus between the posteriodorsal portion of the cephalothorax and the abdomen. Here the isthmus is covered with a

rchmentlike chitinous membrane that is one of the t parts to slough away during ecdysis, thus freeing tag and allowing its retention after the crab lts. Tagging mortality and initial tag loss are all. Tags are recovered by the commercial fishery, l "on-the-spot" rewards are paid. Analysis of a is facilitated by use of IBM punch-card methods.

References

ASKA DEPARTMENT OF FISHERIES 1954. 1954 nnual Report (Report No. 6). Alaska Dept. of Fish., Juneau. 2 p.

BRIGHT, DONALD B., DURHAM, FLOYD E., and KNUDSEN, JENS W. 1960. King crab investigations of Cook Inlet, *Alaska. Dept. of Biology*, Allan Hancock Fdn 180 p. (Processed).

MARUKAWA, HISATOSHI 1933. Biological and fishery research on the Japanese king crab *Paralithodes camtschatica* (Tilesius). *J. Imp. Fish. Exp. Sta.*, Tokyo, No. 4, Paper No. 37, 152 p. (In Japanese with English abstract).

POWELL, GUY C. 1960. Investigation of the growth rates of king crab in the Kodiak area. *Alaska. Dept. of Fish and Game*, 43 p. (Processed).

WEBER, DOUGLAS D., and MIYAHARA, TAKASHI 1962. Growth of the adult male king crab *Paralithodes camtschatica* (Tilesius) population. *Fish. Bull. U. S.*, **62** (200): 53—75.

Schmidt & Klaunig, Kiel

Schools of yellowfin tuna (*Thunnus albacares*) in the eastern tropical Pacific are often associated with porpoise of the genus *Stenella*. Owing to this association, the Bureau of Commercial Fisheries in conjunction with its studies of tuna behavior recently has begun observations on the ecology and behavior of these porpoise.

One species of *Stenella*, called "spinners" or "spinner porpoise" by tuna fishermen, commonly exhibits a striking jumping behavior, the animals revolving rapidly about their longitudinal axes as they leap (Fig. 1). Specimens of these porpoise were collected and shipped to the U. S. National Museum. Dr. Charles O. Handley, Jr., tentatively identified them as *Stenella microps* Gray.

Motion pictures were taken of the jumping and spinning behavior of *S. microps*. Copies are on deposit with the U. S. National Museum, the University of California, Los Angeles, and the Bureau of Commercial Fisheries Biological Laboratory, San Diego. These films were studied and used in conjunction with field notes to analyze the jumping behavior.

Two types of jumping behavior were distinguished. The first was a combination of forward motion and the upward movement necessary to bring the blowhole clear of the water. Quiet animals traveling slowly often simply moved close enough to the surface to expose the blowhole and submerged again. As swimming speed increased, the amount of the body exposed increased until, at moderate speeds, the entire animal was out of the water.

The second type of jumping behavior differed from the former in the following ways: the angle of departure from the water was usually much greater; the duration of the jump was increased manyfold; and the animal rotated rapidly on its longitudinal axis. The longest airborne time we recorded on film was 1.25 seconds. Using the laws of accelerated motion and assuming the leap to be vertical, we calculated a height for the jump of a little over 6 feet and an escape velocity of 20 feet per second or nearly 14 miles per hour. Quite frequently the animals did not clear the water completely and spinning occurred with the tail submerged. The animals often made several spinning jumps in sequence. Clockwise and counterclockwise rotation appeared equally prevalent. The same animal sometimes rotated in a reversed direction on subsequent leaps. Reentry into the water was invariably rostrum first.

Spinning was observed most frequently in slowly swimming groups and least frequently in stampeding herds. In stampedes the frequency and height of respiratory jumps increased such that the water was churned to a froth and spinning jumps were infrequent. These herds appeared to be swimming rapidly. However, when timed from an outboard skiff, we found that they were swimming only 16 miles per hour.

Remoras frequently were seen attached to swimming porpoise and we at first believed spinning might be an attempt to dislodge them. Careful study of the films, however, failed to confirm this hypothesis. Not all those which spun had remoras. Courtship display also

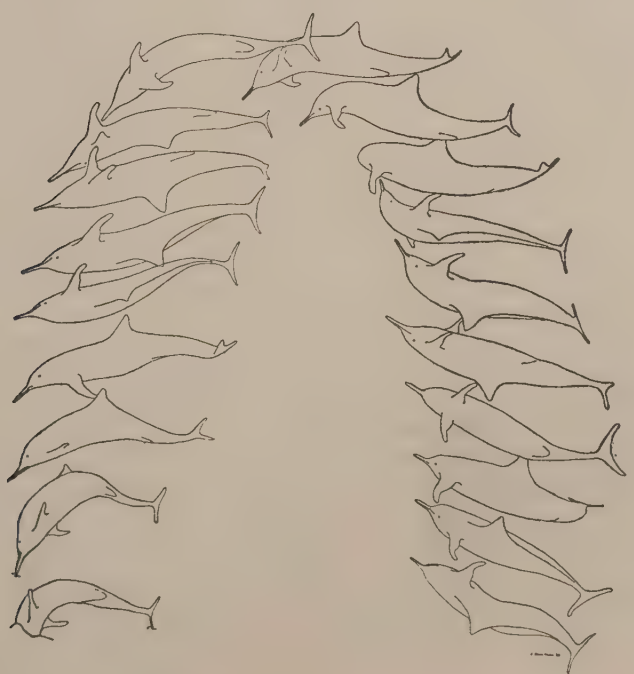

FIG. 1.—Frame-by-frame composite of a spinning sequence in a young male. Two and

was rejected as a possible cause when spinning was found in mature and immature animals of both sexes. Some other explanation must be sought for this behavior.—F. J. Hester, J. R. Hunter and R. R. Whitney, *Tuna Behavior Investigation, Bureau of Commercial Fisheries Biological Laboratory, San Diego, California. Received 20 October 1962.*

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Preliminary Report on the Marquesan Sardine, *Harengula vittata,* in Hawaii

THOMAS S. HIDA and ROBERT A. MORRIS[1]

THE MARQUESAN SARDINE, *Harengula vittata,* was introduced to Hawaiian waters in eight plantings from 1955 through 1959 by the Bureau of Commercial Fisheries in an attempt to establish this species as a supplementary bait fish for skipjack fishing. The details of the first seven introductions have been reported by Murphy (1960) and the eighth by Brock (1960). The eighth introduction comprised an estimated 4,000 sardines ranging from 7.0 to 9.4 cm in standard length[2] and averaging 8.2 cm. This brought the estimated total number of sardines introduced to Hawaii to 144,000. All of the releases have been made around the island of Oahu (Fig. 1).

SOURCES OF INFORMATION

The introduction of the sardines was publicized by means of posters and letters. Commercial and sport fishermen and game wardens were asked to cooperate in supplying information on sightings and captures. Jars of formalin and labels for recording data concerning captures were supplied to the game wardens and the skipjack fishermen, whose bait nets were considered a likely source of specimens. From 1956 through 1960, 54 samples comprising 336 fish were turned in, the majority of them by skipjack fishermen.

DISTRIBUTION

Recaptures of Marquesan sardines have been reported from six of the eight major islands in Hawaii (Fig. 2). The lack of reports from Lanai and Niihau may be due to the fact that skipjack fishermen rarely fish for bait in the waters around those islands.

Table 1 lists all the sardine recoveries from the Hawaiian Islands. The first recapture was made in Keehi Lagoon, Honolulu, in 1956. Subsequent recoveries were from Barber's Point and Kaneohe Bay, Oahu, in 1957. In 1958 sardines were taken at the islands of Kauai and Maui, where no releases had been made, and also in Honolulu Harbor and Pearl Harbor, Oahu, for the first time. In 1959 the sardine was reported from the islands of Hawaii and Kahoolawe, and for the first time from Haleiwa, Oahu. The first specimens from Molokai and from Nawiliwili and Hanamaulu bays, Kauai, came in 1960. Sardines have been taken from both the leeward and windward shores of Oahu and Kauai but only from the leeward shores of Hawaii, Maui, Kahoolawe, and Molokai (Fig. 2).

Neither our knowledge of the life history of this species nor our observations of it in Hawaiian waters are adequate to tell us whether the extension of its distribution from Oahu to the other islands has come about through migration of the adults across the channels or through the drifting of eggs or larvae with the currents.

The habitat occupied by the sardine seems to coincide with that of the nehu, *Stolephorus purpureus,* the most commonly used tuna bait fish in Hawaii. This distribution pattern may be only a sampling artifact, since most of the fishing with gear likely to take sardines is done by skipjack fishermen fishing for nehu. However, because of the chronic shortage of tuna bait in Hawaii, the fishermen are alert for reports of bait supplies even in areas outside the usual nehu fishing grounds. If sardines were present in conspicuous abundance in any accessible area, it appears highly probable that the fishermen

[1] U. S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii. Manuscript received May 21, 1962.

[2] All of the length measurements appearing in this report are expressed in standard length, which is the distance from the tip of the snout to the end of the hypural.

TABLE 1

RECORDS OF MARQUESAN SARDINES COLLECTED IN HAWAII

LOCALITY	DATE OF CAPTURE	METHOD OF CAPTURE	NUMBER CAUGHT	NUMBER PRESERVED	STANDARD LENGTH (cm)	
					Range	Mean
Oahu I.						
Keehi Lagoon	9/27/56	night net[1]	....	1	9.97–	9.97
	3/27/57	night net[1]	....	1	8.50–	8.50
	10/4/59	night net[1]	est. 500	17	3.59–5.60	4.40
	11/3/59	night net[1]	....	7	5.25–5.68	5.46
	11/5/59	night net[1]	....	27	4.08–6.07	4.88
	11/25/59	night net[1]	....	16	4.03–6.46	5.51
	12/1/59	(?)	....	2	3.05–3.51	3.28
	7/20/60	day seine	est. 3	1	2.92–	2.92
	9/14/60	day seine	....	3	3.39–4.72	4.27
Kaneohe Bay	3/26/57	day seine	est. 7	1	8.75–	8.75
	4/8/57	night net	....	4	8.07–8.75	8.46
	6/4/57	night net	....	1	9.50–	9.50
	6/30/58	(?)	....	1	9.75–	9.75
	9/23/58	day seine	....	1	5.60–	5.60
	11/3/58	day seine	....	1	3.46–	3.46
	11/27/58	day seine	est. 12	6	3.53–4.30	3.96
	7/20/59	day seine	16	8	4.30–13.21	7.66
	9/4/59	day seine	....	2	4.90–8.56	6.73
	9/6/59	day seine	....	2	3.04–3.22	3.13
	9/11/59	day seine	....	1	8.30–	8.30
	9/14/59	day seine	....	2	8.21–8.67	8.44
	10/2/59	day seine	....	1	5.40–	5.40
	2/26/60	day seine	....	1	12.01–	12.01
	6/9/60	day seine	....	2	3.34–3.68	3.51
Barbers Point	9/9/57	gill net	....	6	11.20–13.50	12.55
Honolulu Harbor	2/28/58	night net	....	4	7.71–9.40	8.72
	6/27/58	night net	....	1	9.54–	9.55
Pearl Harbor	4/29/58	day seine	....	3	10.05–10.71	10.45
Haleiwa	9/2/59	day seine	....	11	4.46–6.10	5.27
	6/22/60	day seine	est. 20	5	3.98–5.14	4.54
	7/22/60	day seine	....	2	4.71–8.64	6.67
Maui I.						
Kihei	7/5/58	(?)	1	10	not exam.	not exam
	10/7/58	day seine	....	29	3.49–5.32	4.67
	11/3/58	day seine	....	4	6.32–7.00	6.59
	5/19/59	day seine	est. 6	1	9.12–	9.12
	5/28/59	day seine	....	7	9.10–10.91	9.91
	5/29/59	day seine	....	2	9.29–10.83	10.06
	6/2/59	day seine	....	1	8.56–	8.56
Maalaea Bay	8/13/59	day seine	....	3	5.62–6.00	5.87

[1] The net used in Hawaii for taking tuna bait at night is a rectangular lift net pulled under the fish which are attracted to an underwater light suspended alongside the fishing boat.

[2] A "bucket" of bait in the Hawaiian skipjack fishery is estimated to represent about 7 lb of fish.

TABLE 1—*Continued*

LOCALITY	DATE OF CAPTURE	METHOD OF CAPTURE	NUMBER CAUGHT	NUMBER PRESERVED	STANDARD LENGTH (cm)	
					Range	Mean
Kauai I.						
Port Allen	9/10/58	night net	....	6	6.17–6.69	6.41
	10/2/58	night net	....	6	3.90–7.90	6.60
	5/24/60	day seine	est. 100	3	3.80–7.34	5.05
	7/5/60	day seine	est. 500	10	4.00–6.87	5.45
	7/9/60	day seine	est. 100	58	5.85–8.75	7.24
	7/23/60	day seine	est. 20	7	4.67–5.99	5.54
Hanalei Bay	9/25/58	(?)	....	6	6.90–7.90	7.50
Waimea Bay	1/?/59	pole-and-line	....	2	9.80–11.48	10.64
	10/14/59	pole-and-line	....	1	14.62–	14.62
	7/23/60	day seine	est. 40	2	11.34–13.30	12.32
Nawiliwili Harbor	6/2/60	night net	....	8	10.57–12.47	11.75
Hanamaulu Bay	9/6/60	gill net	....	1	12.21–	12.21
Hawaii I.						
Kawaihae Bay	3/14/59	day seine	est. 3 bkts.[2]	12	7.56–10.05	8.73
Kahoolawe I.						
SW Point	6/17/59	day seine	est. ½ bkt.	11	9.76–12.08	10.83
Molokai I.						
Laau Point	9/3/60	day seine	....	5	5.61–6.70	5.80

would find them. The main nehu baiting areas are in the relatively protected waters of bays, harbors, and canals where the water is brackish and turbid owing to the influx of streams and ground water. The Kihei area on the island of Maui and Waimea on Kauai are exceptions, the baiting grounds being exposed to the open ocean and moderate surf action. Baiting, in general, is done close to shore in shallow water, although night-lighting for bait may be done in deeper waters of channels and harbors. Since it appears that the sardine has established itself in the nehu grounds, it is important, from the standpoint of the tuna fishery, to keep a close watch on the population trend of the species in Hawaii and the effect that it may have on the bait supply in the future.

ABUNDANCE

Our only source of information on the abundance of sardines in Hawaiian waters has been the reports of observations by commercial and sport fishermen. The numbers of specimens turned in by fishermen are not a good index of abundance, because often they are only a small and arbitrarily selected fraction of the catch. There have also been times when sardines were seen but not caught.

The first observation of a large school of sardines, 20 to 30 buckets,[3] was made in Waimea, Kauai, late in the summer of 1958 by skip-

[3] A "bucket," the unit commonly used by skipjack fishermen for measuring bait, contains an average of 7 lb of fish.

The food habits of the larger and smaller sardines appeared to be essentially similar, but fish larvae were found only in sardines 8.0 cm long or larger, and there seemed to be a size-associated difference in the composition of the copepod component of the diet. The smaller fish fed more commonly on small cyclopoid copepods, such as *Corycaeus* sp. and *Oncaea* sp., while the larger sardines had more often been feeding on larger calanoids, such as *Candacia* sp., *Labidocera* sp., and *Pleuromamma* sp. The samples were inadequate to carry on a detailed study of food habits among the different areas.

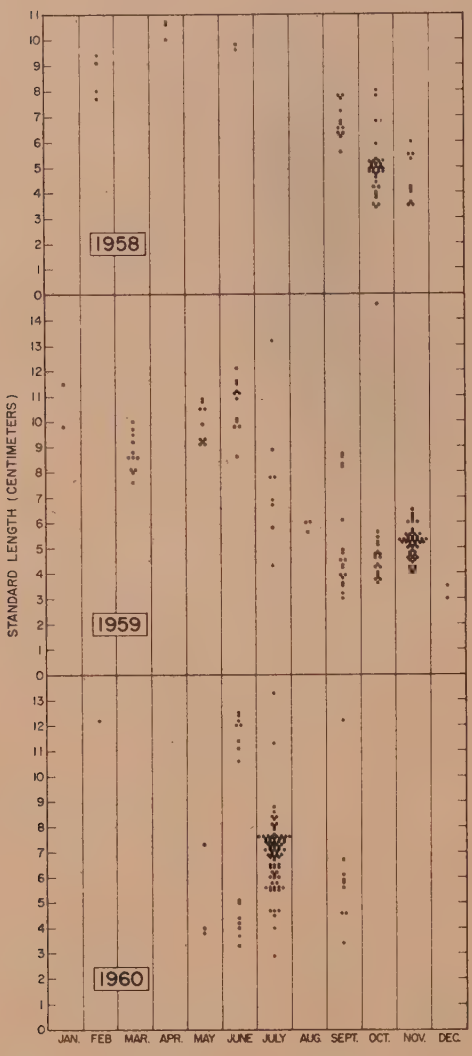

FIG. 3. Size frequencies of sardines collected in Hawaii in 1958, 1959, and 1960.

As indicated in Table 2, 17% of the stomachs with food had fish larvae in them. Of 34 fish larvae found, 24 (71%) were identified as nehu. The largest number of larval nehu found in a stomach was 6, in a 10.8-cm specimen from Kihei, Maui. The largest nehu found measured 3.3 cm, in a 9.4-cm sardine, also from Kihei, Maui.

The food habits of *H. vittata* in its native environment were extensively studied by Nakamura and Wilson (MS). They also found copepods to be the most frequently occurring organism (79.1%), followed by pelecypods, gastropods, barnacle cypris, pteropods, amphipods, and megalops. Fish larvae occurred in only 1.6% of the stomachs. The only distinct difference between the feeding habits of the species in Hawaii and in the Marquesas seems to be the low percentage of occurrence of fish larvae in the Marquesan fish.

The food habits of the sardine in Hawaii are similar to those of the nehu, both species feeding largely on the crustacean elements in the plankton. Hiatt (1951) found that nehu feed primarily on copepods, barnacle larvae, mysis larvae of shrimps, ghost shrimp (*Lucifer* sp.), crab larvae, and palaemonid shrimps.

SPAWNING

The size of the first sardines taken at Maui and Kauai in 1958 was such that, as pointed out by Murphy (1960), it seemed more likely that they were the products of spawning in Hawaiian waters rather than members of the original transplanted stock. A collection of 29 sardines taken at Kihei, Maui, in October, 1958, contained 7 measuring less than 4.3 cm, which was the length of the smallest sardine measured in the release of May, 1958. Subsequently, sardines smaller than 4.3 cm were taken in Keehi Lagoon and Kaneohe Bay in July, September, October, November, and December, 1959 (Fig. 3). In 1960, small sardines were caught at Keehi Lagoon, Kaneohe Bay, and Haleiwa on Oahu, and at Port Allen, Kauai, in May, June, July, and September.

Nakamura and Wilson (MS) have reported that in the Marquesas 8.4 cm, plus or minus 1.7 cm, is the mean length of females at sexual maturity. They considered that year-round occurrence of ovarian eggs of 0.6 mm or larger diameter indicated that sardines spawn throughout the year in Marquesan waters. Although our Hawaiian samples were inadequate for determination of the spawning season of the introduced fish, the occurrence of ova 0.43 to 0.74 mm in diameter in sardines taken in May, June, July, September, and October and the appearance of small sardines from May through December lead us to believe that the species also has a prolonged spawning period in Hawaii.

SUMMARY

Eight releases of the Marquesan sardine, *Harengula vittata,* have been made around the island of Oahu in the hope that it would become established and sufficiently abundant to increase the tuna bait fish supply. An estimated 144,000 individuals were released from 1955 through 1959. Recoveries by skipjack fishermen have been made from all of the major islands except two. The habitat occupied by the sardine seems to coincide with that of the most important native bait fish, the nehu (*Stolephorus purpureus*). The occurrence of young sardines since 1958 indicates that they have spawned successfully, but the species is not yet making any significant contribution as a bait fish. The sardines feed primarily on copepods, and also eat gastropod larvae, larval and adult shrimps, crab larvae, fish larvae, amphipods, and polychaetes. This diet is similar to that of the nehu.

REFERENCES

BROCK, VERNON E. 1960. The introduction of aquatic animals into Hawaiian waters. Int. Rev. Hydrobiol. 45(4):463–480.

HIATT, ROBERT W. 1951. Food and feeding habits of the nehu, *Stolephorus purpureus* Fowler. Pacif. Sci. 5(4):347–358.

MURPHY, GARTH I. 1960. Introduction of the Marquesan sardine, *Harengula vittata* (Cuvier and Valenciennes), to Hawaiian waters. Pacif. Sci. 14(2):185–187.

NAKAMURA, EUGENE L., and ROBERT C. WILSON. MS. The distribution and biology of the Marquesan sardine. Bu. of Comm. Fish. Bio. Lab., Honolulu.

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